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ABSTRACT

This document consists of materials for a 12-unit course on the following topics: (1) introduction to milling; (2) structure and accessories; (3) safety and maintenance; (4) cutting-tool variables; (5) basic set-up activities; (6) squaring a workpiece; (7) hole-making operations; (8) form milling; (9) machining keyways; (10) milling angular surfaces; (11) rotary tables and indexing; and (12) horizontal milling operations. The instructor's guide begins with a list of competencies covered in the module, descriptions of the materials included, an explanation of how to use the materials, and information on how the curriculum guide is packaged. Next is a table that associates individual instructional materials in the units with the competencies they teach. The instructional units follow, each of which may include unit objectives, lesson objectives, lesson plans, references, notes to the teacher, information sheets or outlines, transparency masters, handouts, assignment sheets, job sheets, unit tests, and answers to tests. (CML)

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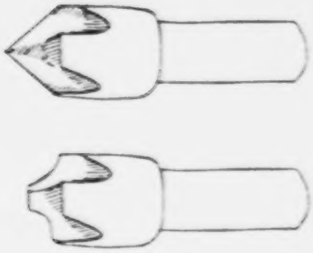
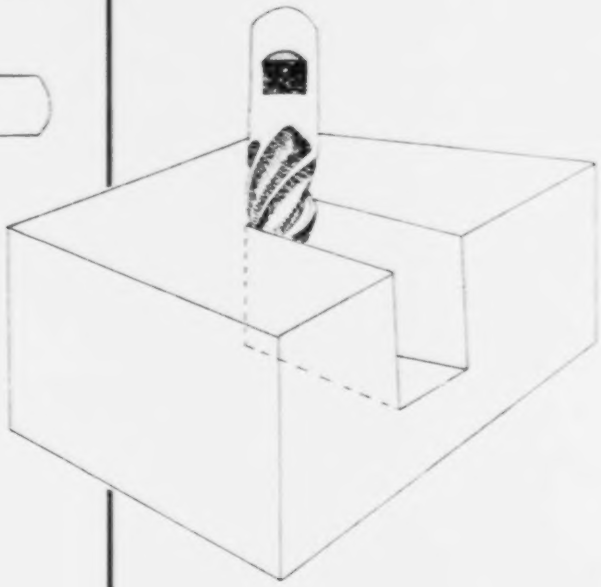
MACHINE SHOP CURRICULUM

INSTRUCTOR'S GUIDE

MODULE 6: Milling





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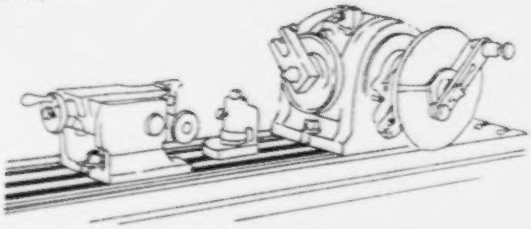

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Modules in this IML Machine Shop series

1: *Machine Shop Orientation and Math* by Donna Curtis and Jack Nobles
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3: *Bench Work and Material Science* by Charles H. Walden and Jack Nobles
4: *Power Saw and Drill Press Operation* by Charles H. Walden and Bill Daniel
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6: *Milling* by Charles H. Walden
7: *Grinders* by Jack Nobles and Mel Gage
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MACHINE SHOP

Module 6: Milling

by

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1989

Instructor's Guide
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FOREWORD

Once again, we are indebted to the teachers and administrators who provide their time, efforts and professionalism to develop curriculum for trade, technical and industrial education programs. This Machine Shop guide is an outstanding example of what can be accomplished when the right people with the right attitude get together. Committee members worked hard over several years' time in advisory, writing, technical consultation and field-test capacities.

This guide is designed to be totally integrated with the Vocational Instructional Management System. It is hoped that all guides produced under our supervision will help classroom teachers manage instruction. A curriculum guide is more than a resource--it is an integral part of the management system. Rather than impeding instruction, it should guide and facilitate instruction.

This guide's format has been set up for competency-based teaching and testing. Unit tests evaluate specific competencies and can be used with the Vocational Administrative Management System (VAMS). Information sheets, transparency masters, job sheets, assignment sheets and test items are keyed to specific competencies. A cross-reference table has been included to quickly identify parts of the curriculum that relate to specific competencies. The material has also been packaged for students.

Although this guide may be a new format for some teachers, we are confident that, when used as designed, time spent by teachers and students will become more productive. Any future machine shop curriculum modifications will begin with this guide. The machine shop field is undergoing considerable change. We will annually evaluate the need to update this guide on a module-by-module basis. Your suggestions regarding areas for improvement are both encouraged and appreciated.

Judith Moore, supervisor
Industrial Education
Department of Elementary and Secondary Education

Charles "Chuck" Waibel, director
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Department of Elementary and Secondary Education

ACKNOWLEDGMENTS

This Machine Shop guide represents a continuing commitment to Missouri's Vocational Instructional Management System (VIMS). The guide has been keyed to the machine shop competency profile developed by industry and education professionals in the state.

Appreciation is given to the writers (Charlie Walden, Jack Nobles, Dwight Crosswhite, Donna Curtis, Don Marquardt, Bill Daniel, Mel Gage and Jr. Cagle) for their technical expertise. Catherine Smith of Dodge Art Works, Columbia, created a large portion of the guide's artwork.

These industry representatives and educators contributed to the guide as members of the advisory committee.

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Mel Gage, Linn Technical College
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Support and contributions of IML staff members were instrumental to this module's development.

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Phyllis Miller and Dan Stapleton, assistant directors
Sharon Dyer, graphic artist
Donna Curtis and Lori Holliday, word processors
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Wei Li, graduate assistant

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COMPETENCIES ADDRESSED IN THIS MODULE

J. Operating Milling Machines

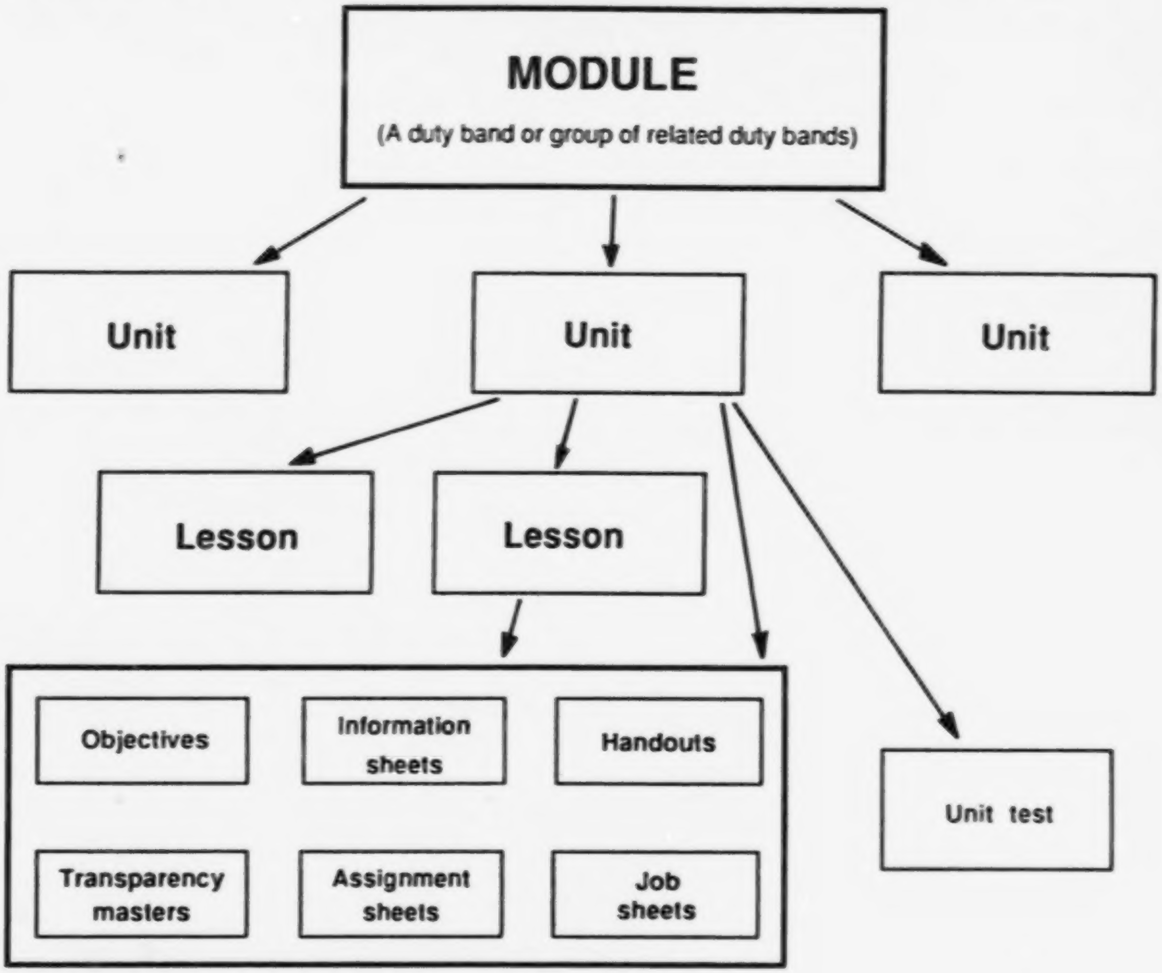
1. Employ milling machine safety guidelines consistently
2. Perform care and maintenance
3. Align mill head to table
4. Align milling machine attachments
5. Align workpiece mounted on machine table
6. Calculate proper feeds and speeds and set up mill accordingly
7. Select and apply proper cutting fluids
8. Determine cutting tool variables prior to use
9. Square workpiece using table vise
10. Mill workpiece with end mill
11. Locate work with edge finder
12. Drill holes with milling machine
13. Ream holes
14. Bore holes with milling machine
15. Form mill workpiece
16. Machine workpiece mounted on V-blocks
17. Machine external straight keyway
18. Machine woodruff keyway
19. Mill angular surfaces
20. Mill an external radius with rotary table
21. Mill internal radius with rotary table
22. Mill workpiece using simple indexing operation
23. Use digital readout
24. Machine workpiece by straddle milling
25. Perform gang milling
26. Perform gear cutting operations (rack and spur)

HOW TO USE THIS PUBLICATION

GUIDE COMPONENTS

Units of instruction

This Machine Shop guide contains eight modules of instruction. Within each module are instructional units including some or all of the following components: performance objectives, information sheets, transparency masters, handouts, assignment sheets, job sheets and a unit test. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section near the beginning of each unit.


MODULE
(A duty band or group of related duty bands)
Unit
Unit
Unit
Lesson
Lesson
Objectives
Information sheets
Handouts
Transparency masters
Assignment sheets
Job sheets
Unit test

Competency profile

On the Missouri competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral. To evaluate the student on performance of the competencies, a 3-2-1-N grading system is used, where:

3 = **Mastery** - can work independently with no supervision
2 = **Requires supervision** - can perform job completely with limited supervision
1 = **Not mastered** - requires instruction and close supervision
N = **No exposure** - no experience or knowledge in this area

Cross-reference table (color-coded white)

Once the numbering system is understood, this table quickly reveals how the instructional components of the module relate to Missouri competencies. On the competency profile, tasks are divided into general subject areas, or duty bands, which are identified by a capital letter. Under each duty band are related tasks (competencies), which are identified by an Arabic numeral.

On the cross-reference table, unit numbers are represented by Roman numerals (I, II, III, etc.). Lessons within a unit are shown with Arabic numerals. Therefore, the first objective in Lesson 1 is numbered 1.1, the second is 1.2, and so on. Other components of the module (transparencies, handouts, assignment sheets and job sheets) also use this numbering system. By looking at the cross-reference table, the instructor can quickly determine what test questions or job sheets a student needs to receive an evaluation on a particular competency.

Objectives (color-coded white)

Each unit is based on performance objectives which state the measurable unit and specific behavioral or performance objectives that students are expected to achieve. Since the objectives of the unit provide direction for the teaching-learning process, it is important for the teacher and students to have a common understanding of the objectives' intent. Teachers should feel free to add/adapt objectives which will fit the material to student and community needs. Supporting material will, of course, need to be added for any new objectives.

Table of contents, references, notes to the instructor (color-coded pink)

These pages have been coded pink for instructor use only. The reference section lists materials used as sources in developing the material. Special instructions on audiovisuals, supplies, etc. are included in the Notes to the Instructor section.

Information sheets (green)

Presented in outline form for clarity, these pages provide content essential for meeting the cognitive (knowledge) objectives in the unit. Students should study the information sheets before class discussion or completion of assignment sheets. **CAUTION** statements indicate possible equipment damage or bodily injury. Handouts and transparency masters have been keyed in the information sheets for instructional use.

Transparency masters (white)

Transparencies provide information by visually reinforcing or clarifying ideas presented in the information sheets. They are effective when identification is necessary and direct the class's attention to the topic of discussion. Transparencies should be left on the screen only when topics shown are under discussion, however.

Handouts (white)

Whenever more detailed information than can be presented in a transparency is needed, a handout is used. Handouts give the students additional information that can be kept with their class notes or student references.

Assignment sheets (tan)

Assignment sheets furnish paper-and-pencil practice to develop the knowledge necessary as a prerequisite to skill development. They can be given to students for class completion or used as homework assignments. Answer sheets (color-coded pink) can be used by the student or instructor to check progress.

Job sheets (blue)

These evaluation instruments are provided for two purposes: to outline steps of procedure and to check student performance mastery. Job sheets begin with a list of tools and materials needed for the activity. Job sheets furnish potential employers with a picture of skills being taught and performance which might be reasonably expected from a vocational student. The spaces to the right of the page on a job sheet assist the instructor in evaluating a student on a particular activity. This 3-2-1-N grading system is the same as the one used on the competency profile.

Unit test (yellow)

Competency-based tests are designed to help eliminate subjective testing and to improve student evaluation and accountability. Specific competencies and test questions are linked on the answer key. These unit tests have been written to be used with computerized VAMS (Vocational Administrative Management System), utilizing Scantron sheets for computer-recording of test answers.

The unit test may be eliminated if the competency was thoroughly evaluated by job sheets. However, an emphasis should be placed on cognitive as well as performance skills. If the objective or competency will be evaluated by a job sheet, it is often necessary to determine by a written test whether the student understands enough of the material to perform the job sheet.

SUGGESTED ACTIVITIES

The following list of suggested activities may be helpful, especially to the beginning instructor.

1. Provide students with objective sheet and information sheets.
2. Discuss unit and specific objectives.
3. Discuss information sheets, assignment sheets and/or job sheets, lesson-by-lesson.
4. Have students do assignment sheet(s) to satisfactory levels.
5. Give students unit test.
6. After successful completion of the test, have students do job sheet(s).

Students should perform the following activities.

1. Read objective sheet.
2. Study information sheets.
3. Do assignment sheet(s).
4. Take unit test.
5. Do job sheets.

PACKAGING

This Machine Shop guide has been packaged with the entire class in mind. For the teacher, a complete instructor's guide contains all eight modules. In the student reference, selected portions have been reproduced for student use (objectives page, information sheets, handouts). Student work sheets (assignment sheets, job sheets, unit tests) have been packaged together for student distribution as the instructor deems necessary.

In the student reference, page numbers do not run consecutively because some pages have been removed that appear only in the instructor's guide.

MODULE 6: MILLING

CROSS-REFERENCE TABLE OF INSTRUCTIONAL MATERIALS

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
J1	III 1.1-1.2	III 1.1,1.2				III 1-3,7	
J2	III 2.1,2.2	III 2.1,2.2			III 2.1	III 4-6	
J3	V 1.1,1.2	V 1.1-1.3			V 1.1		
J4	V 2.1,2.2				V 2.1,2.2		
J5	V 2.3,2.4	V 2.1			V 2.3		
J6	IV 2.1-2.3		IV 2.1	IV 2.1	IV 2.1	IV 12-15	
J7	IV 2.4					IV 10,11	
J8	IV 2.2			IV 2.2	IV 2.1	IV 6,7,9	
J9	VI 1.1,1.2	VI 1.4			VI 1.2	VI 6,7,12	
J10	VI 1.3	VI 1.1-1.3			VI 1.1,1.2	VI 1-5,8-11	
J11	VII 1.2				VII 1.1	VII 2,3,6,7	
J12	VII 1.4				VII 1.3	VII 1,8	
J13	VII 1.5				VII 1.3	VII 1,8	
J14	VII 2.1-2.3				VII 2.1	VII 1,8,11-13	
J15	VIII 1.1-1.4				VIII 1.1	VIII 1-4	
J16	IX 1.1,1.2				IX 1.1	IX 10	
J17	IX 1.1,1.2			IX 1.1	IX 1.1	IX 1-5	
J18	IX 2.1-2.4				IX 2.1	IX 1-3,6-9,11	

Competency	Instructional Objective	Transparency Master	Handout	Assignment Sheet	Job Sheet	Test Item	Notes
J19	X 1.1-3.1				X 1.1-3.1	X 1-5	
J20-21	XI 1.1				XI 1.1	XI 1-3	
J22	XI 2.1-2.3			XI 2.1	XI 2.1	XI 8-14	
J23	VII 1.3				VII 1.2	VII 4,5,9,10	
J24	XII 1.1-1.2				XII 1.1	XII 1,4	
J25	XII 1.3				XII 1.2	XII 2	
J26	XII 2.1-2.5	XII 2.1-2.2	XII 2.1	XII 2.1	XII 2.1	XII 5-20	

MODULE: MILLING

UNIT I: INTRODUCTION

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to define milling machine terms and identify milling machine parts, types, operations and functions. This knowledge will be evidenced by achieving a specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lesson in this unit, the student should be able to:

1.1 Match milling machine terms with definitions.

1.2 Describe the milling process.

1.3 Classify milling machines.

1.4 Identify the specifications needed for milling machines.

1.5 Identify the major components of vertical milling machines.

1.6 Identify the types of milling machine motion.

1.7 Identify milling machine operations.

MODULE: MILLING

UNIT I: INTRODUCTION

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

1. Lesson 1: INTRODUCTION TO MILLING MACHINES

    a. Information outline

    b. Transparency masters

        TM 1.1: The milling process
        TM 1.2: Spindle orientation
        TM 1.3: Bed-type manufacturing mill
        TM 1.4: Knee and column mill
        TM 1.5: Computerized mill
        TM 1.6: Precision jig borer

    c. Assignment sheet

        AS 1.1: Introduction to milling machines

    d. Answers to assignment sheet

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guide

1. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental materials (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

   1. Introduction to the Vertical Milling Machine (MS-84-310) (video). Sedalia, MO: State Fair Community College, 1984.

   2. Introduction to the Horizontal Milling Machine (MS-84-360) (video). Sedalia, MO: State Fair Community College, 1984.

MODULE: MILLING

UNIT I: INTRODUCTION

LESSON 1: INTRODUCTION TO MILLING MACHINES

I. Terms and definitions

  A. Bed-type milling machine--machine used for heavy production work which has a table mounted to a rigid bed

  B. Capacity--total amount of longitudinal travel of the table

  C. Column and knee milling machine--machine which has a table that travels longitudinally on a saddle which travels transversely (crosswise). The saddle is mounted on a knee which can move vertically on the column.

  D. Computerized milling machine--machine equipped with a computer and servo-motors for controlling vertical, transverse and longitudinal movement

  E. Horizontal milling machine--milling machine which has a horizontally oriented spindle

  F. Horsepower--output power rating of the spindle drive motor

  G. Jig-boring machine--ultra-precision vertical milling machine used primarily for locating and creating holes to a very close tolerance

  H. Longitudinal motion--movement of the table from left to right parallel to the face of the column

  I. Model--manufacturer's machine designation

  J. Milling--use of a revolving multi-tooth cutter to shape a workpiece

  K. Milling machine--a machine which is generally used to shape a workpiece with a revolving multi-tooth cutter

  L. Transverse motion--accomplished by moving the saddle in and out from the face of the column

  M. Type--structure of machine (eg. vertical or horizontal, bed or knee and column)

  N. Vertical milling machine--machine which has a spindle oriented vertically

  O. Vertical milling machine applications--the variety of tasks which can be performed on a vertical milling machine including drilling, milling, reaming, indexing and boring, etc.

  P. Vertical motion--accomplished by raising and lowering the knee or raising and lowering the quill

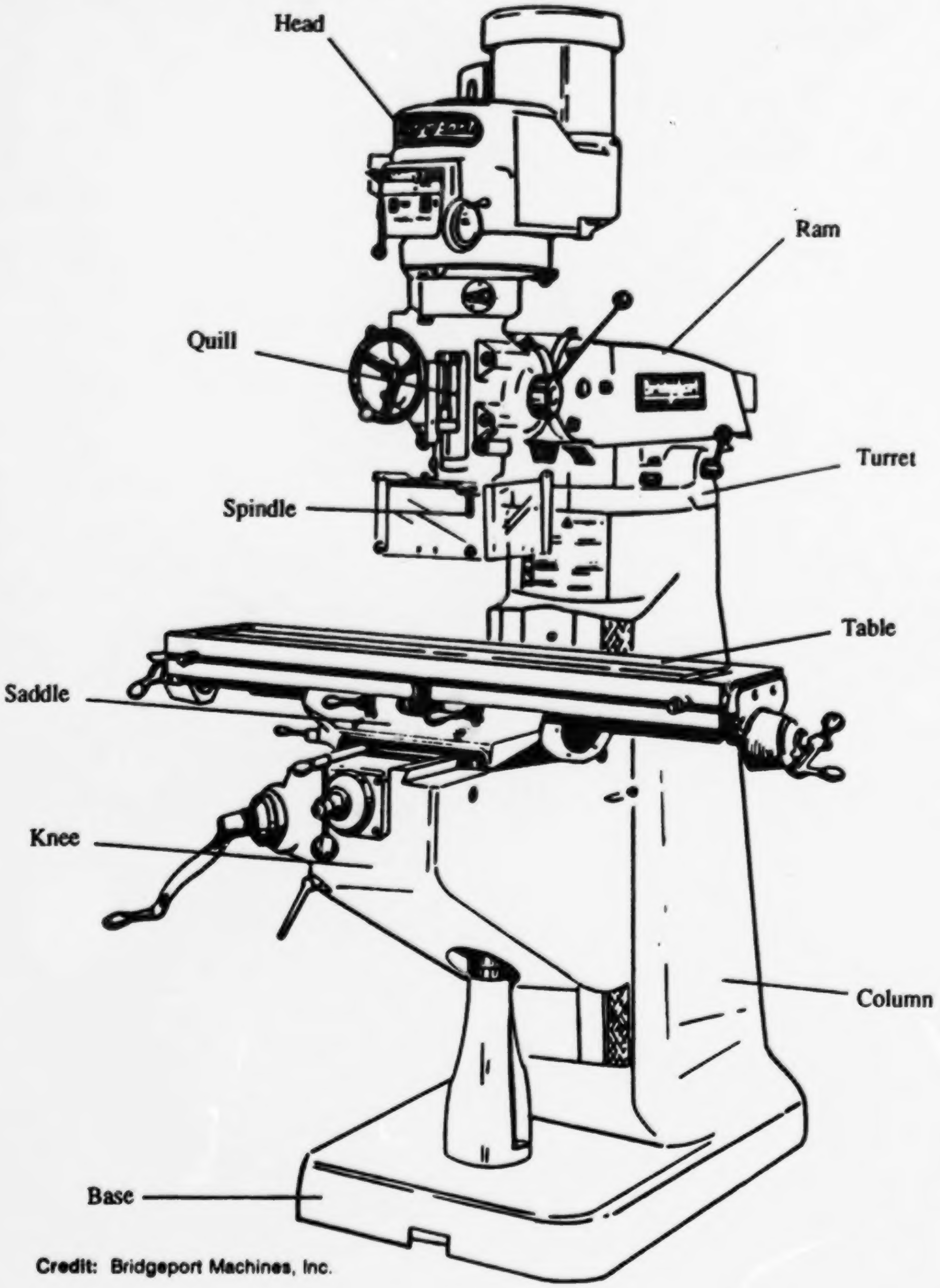
II. Milling process **(TM 1.1)**

  A. Revolving multi-tooth cutter

  B. The workpiece moves and the tool revolves but remains stationary.

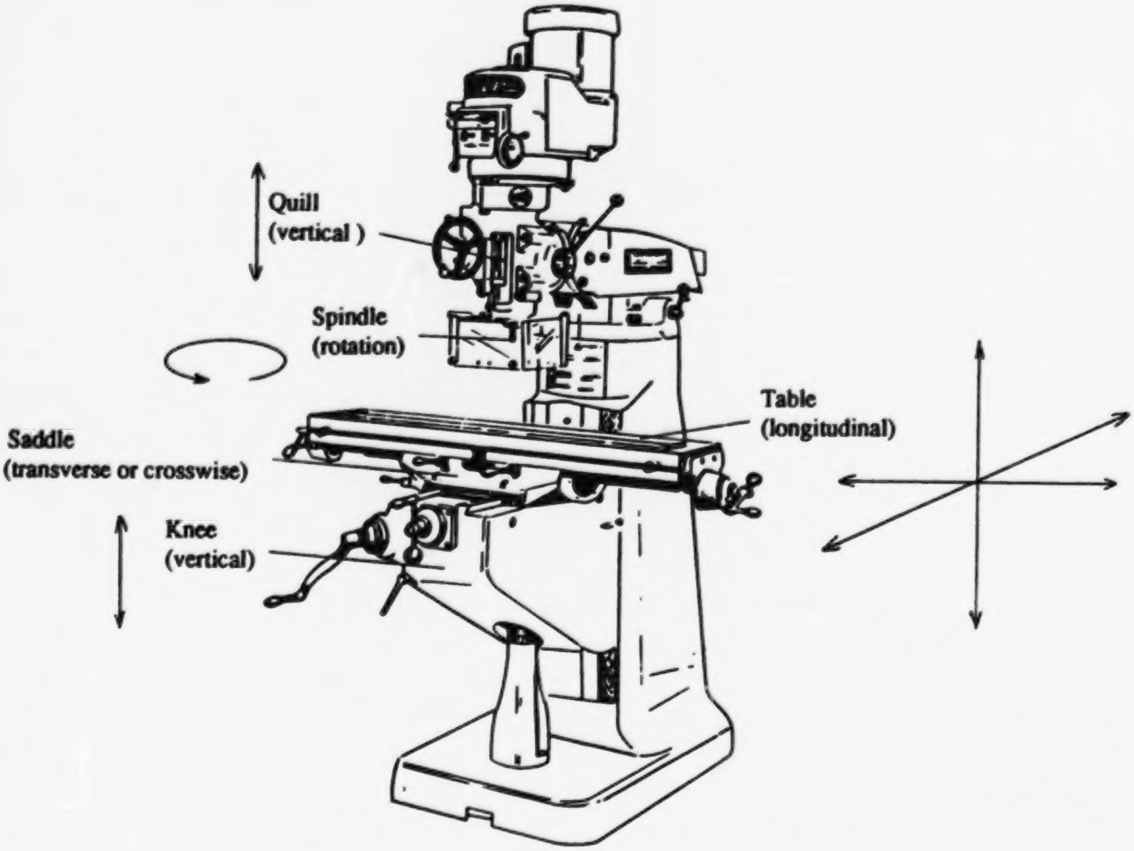
- III. Classification of milling machines **(TM 1.2-1.6)**
  - A. By spindle orientation
    - 1. Vertical
    - 2. Horizontal
  - B. Type
    - 1. Bed
    - 2. Knee and column
  - C. Special-purpose milling machines
    - 1. Computerized milling machine
    - 2. Jig borer
- IV. Milling equipment specifications
  - A. Horsepower
  - B. Type
    - 1. Knee and column or bed
    - 2. Horizontal or vertical
  - C. Model
  - D. Capacity

V. **Major components of vertical milling machines**


Head
Ram
Quill
Turret
Spindle
Table
Saddle
Knee
Column
Base

Credit: Bridgeport Machines, Inc.

VI. Types of milling machine motion


Quill
(vertical)
Spindle
(rotation)
Table
(longitudinal)
Saddle
(transverse or crosswise)
Knee
(vertical)

Credit: Bridgeport Machines, Inc.

VII. Milling machine operations

A. Milling

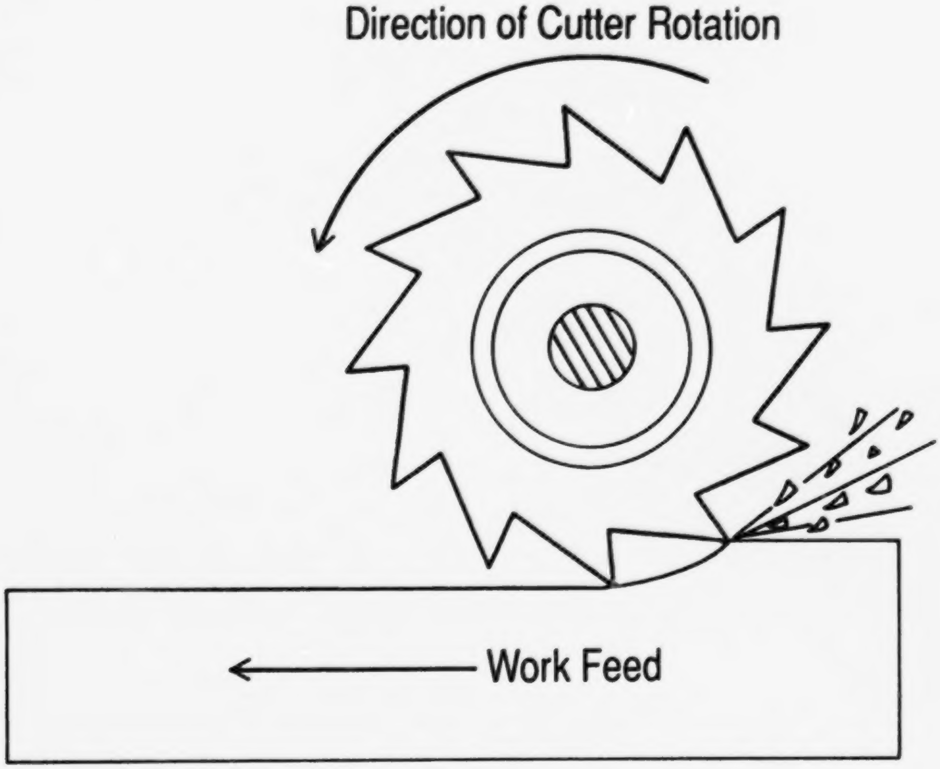
B. Hole operations

1. Drilling
2. Reaming
3. Boring

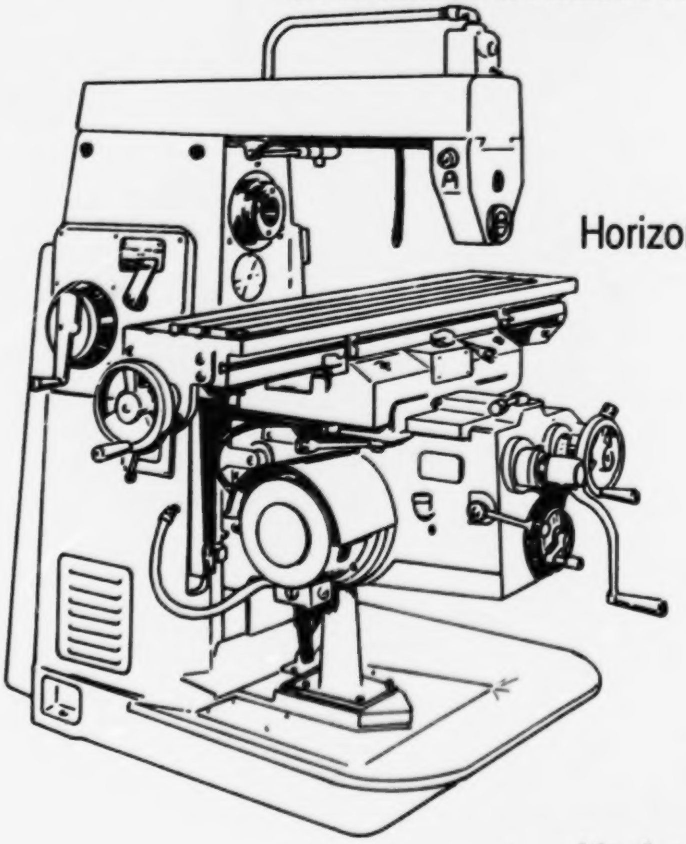
C. Special operations

1. Gear cutting
2. Radius cutting
3. Indexing

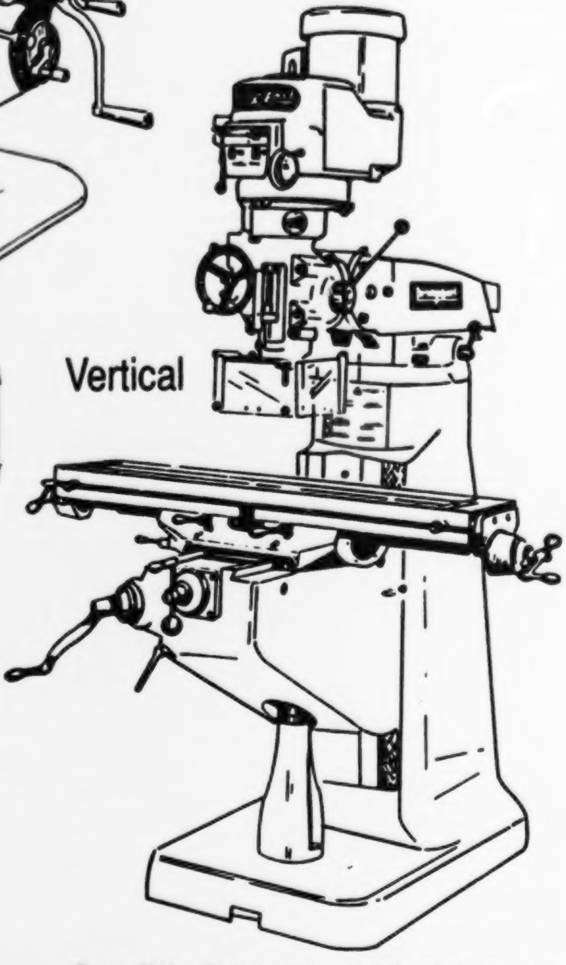
THE MILLING PROCESS


Direction of Cutter Rotation
Work Feed

SPINDLE ORIENTATION

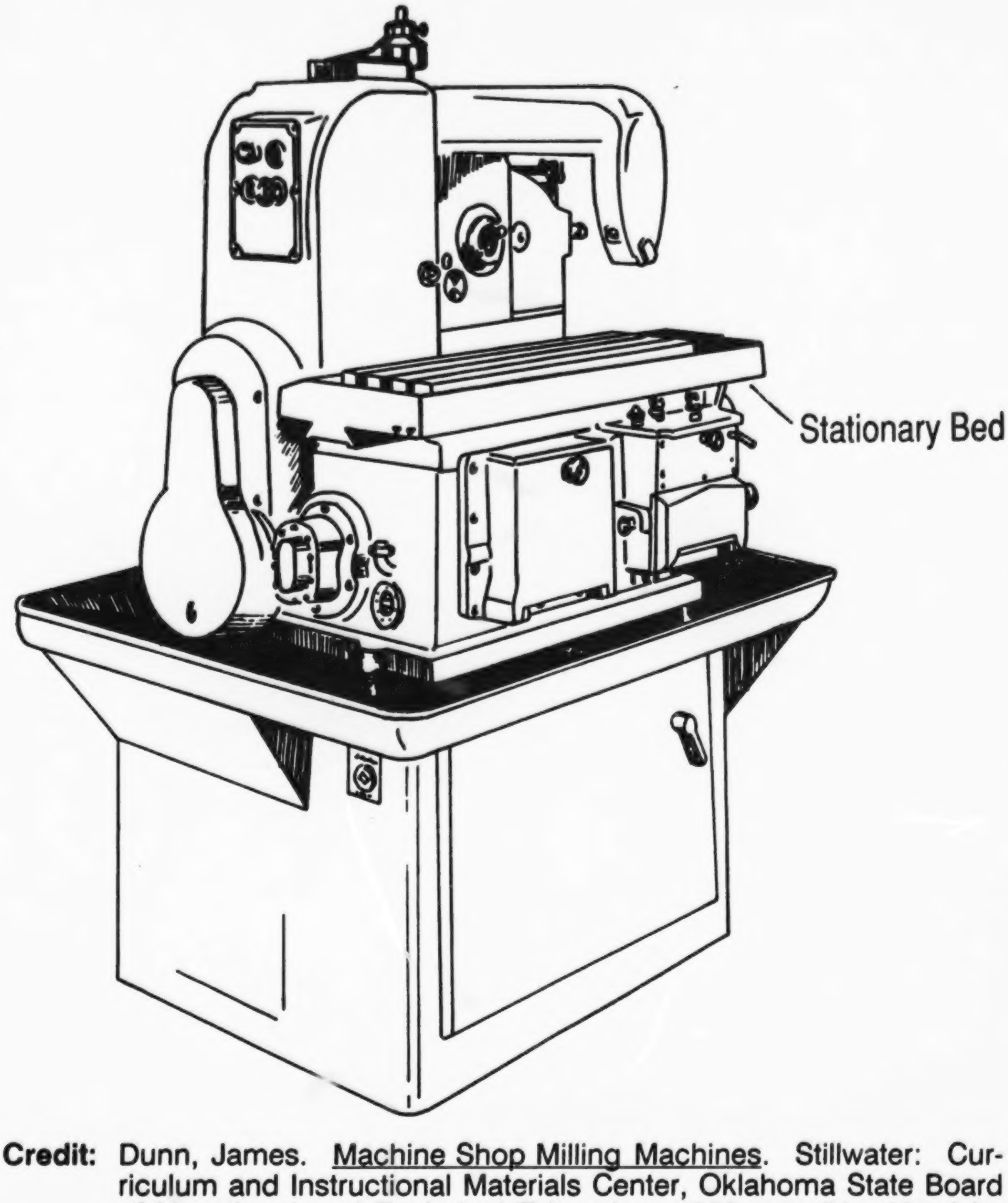

Horizontal ←→

Credit: Cincinnati Milacron



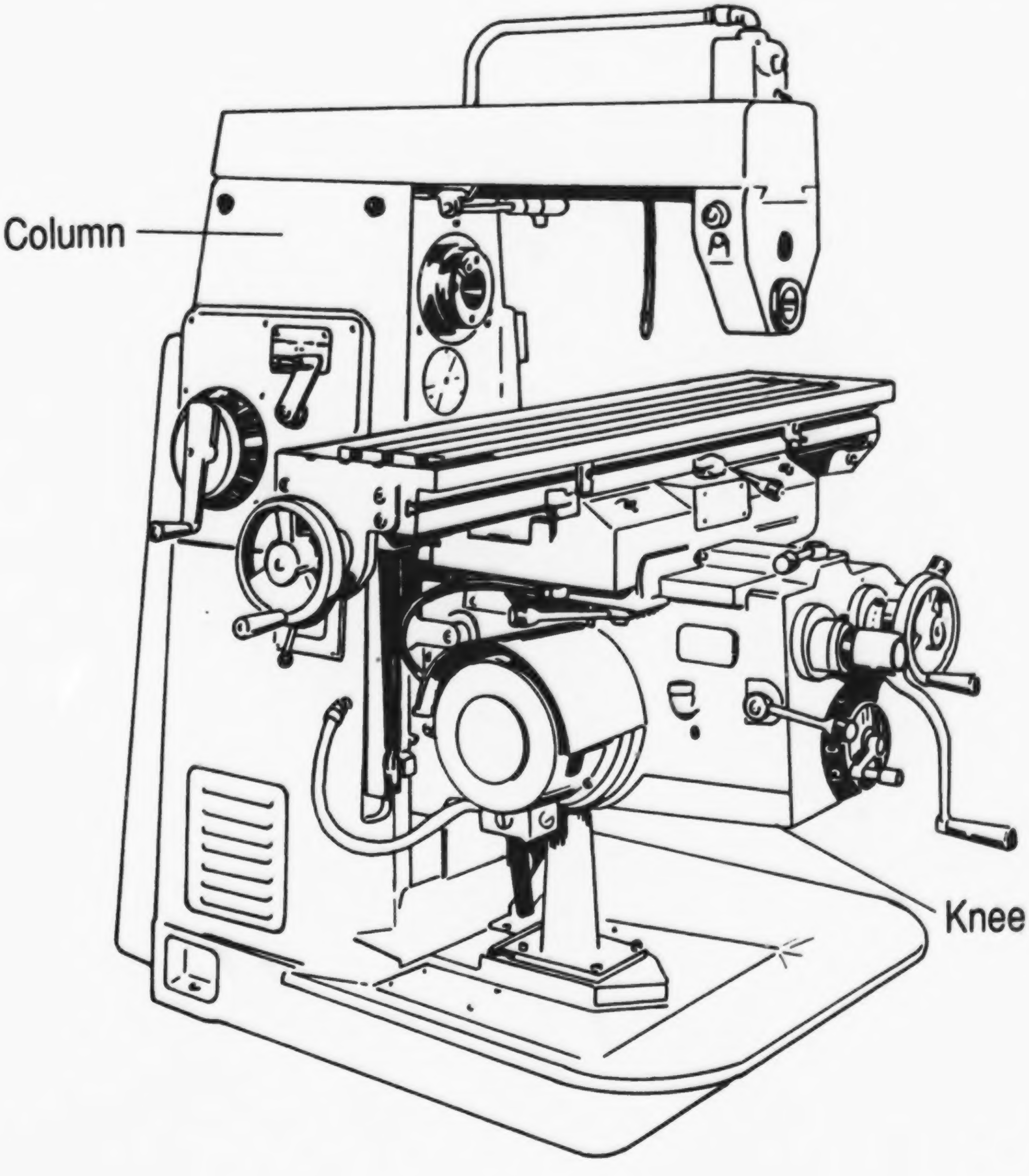
Credit: Bridgeport Machines, Inc.

BED-TYPE MANUFACTURING MILL



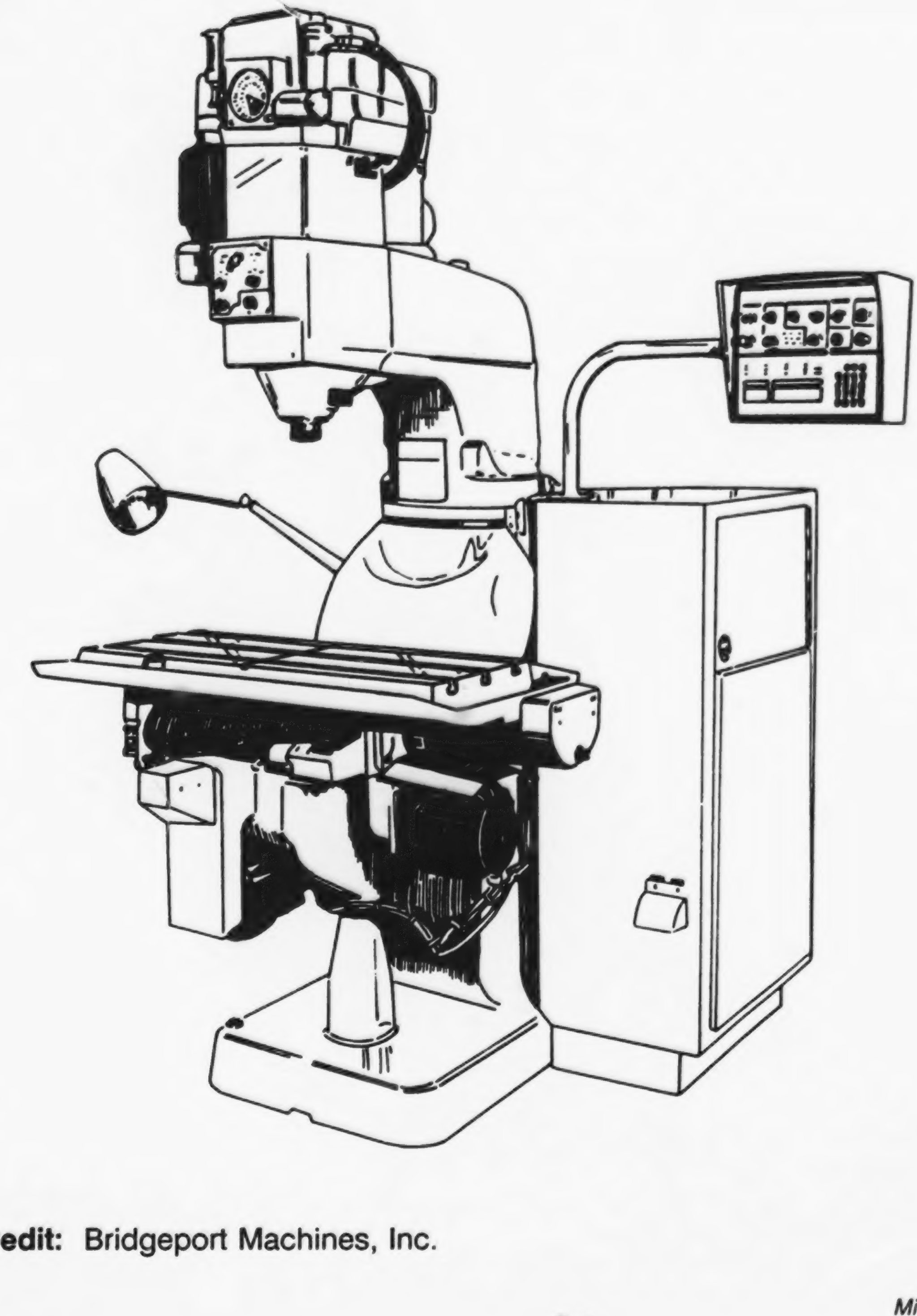
Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 51. Used by permission.

KNEE AND COLUMN MILL


Column
Knee

Credit: Cincinnati Milacron

COMPUTERIZED MILL



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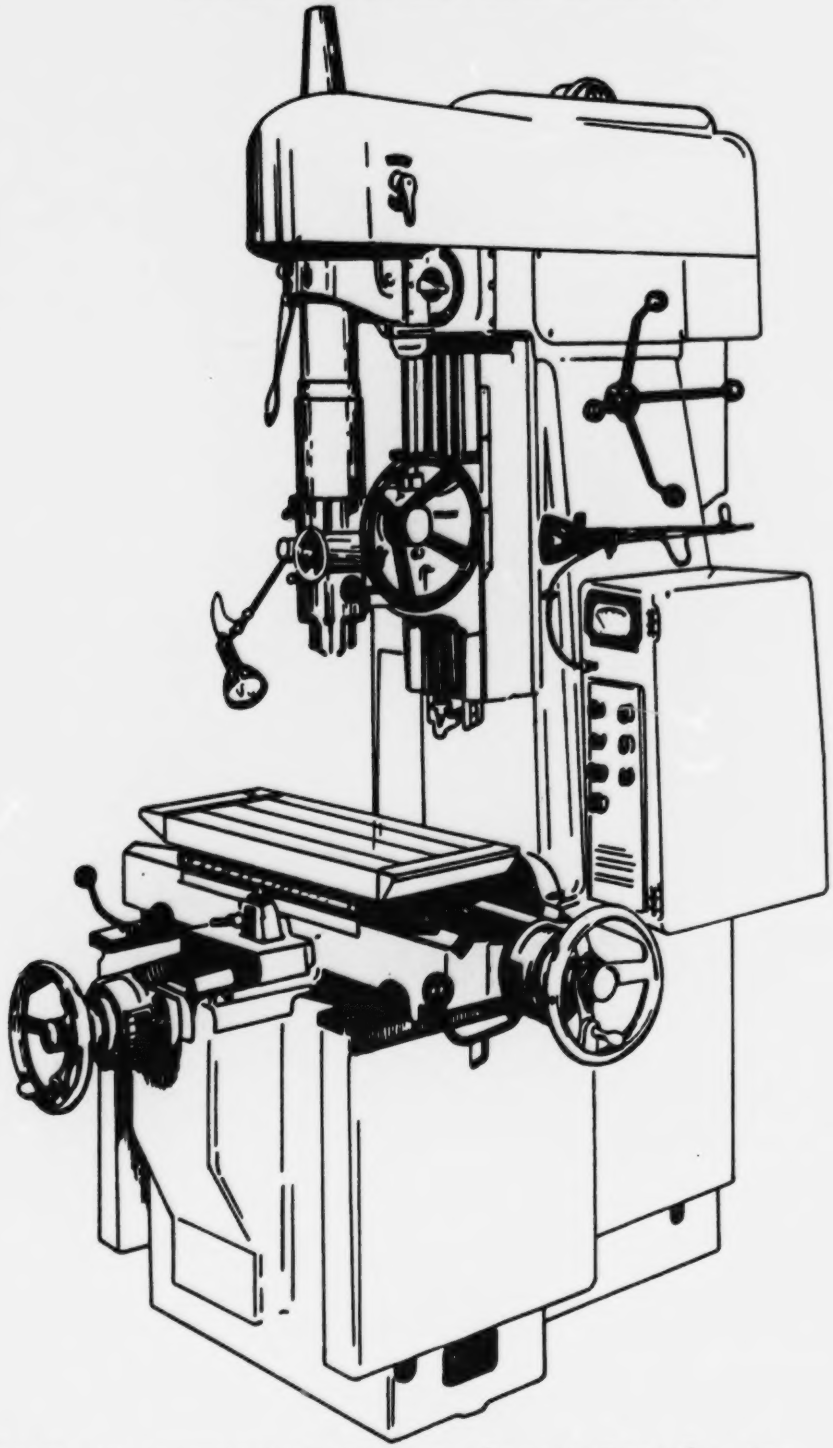
PRECISION JIG BORER



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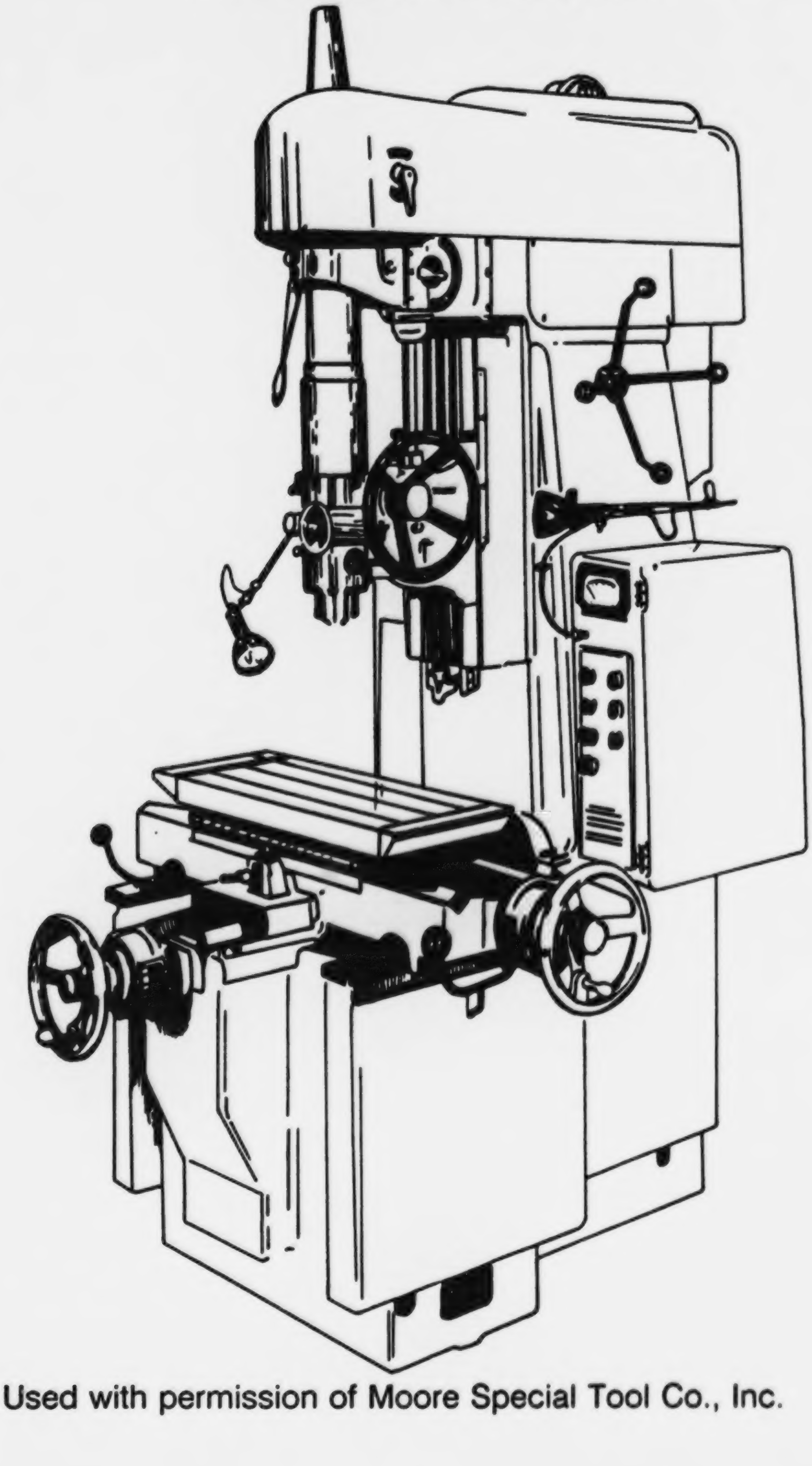
PRECISION JIG BORER



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AS 1.1

INTRODUCTION TO MILLING MACHINES

Complete the sentences below by filling in the blanks with the appropriate word or phrase.

1. In milling, the workpiece moves while the cutter remains __________ .

2. A milling spindle can be oriented in either a __________ or __________ position.

3. A __________ and __________ milling machine features a screw which permits vertical movement of the milling table.

4. A high-precision milling machine used to accurately locate and drill holes is called a ______________ .

5. On a vertical milling machine, vertical (up and down) movement can be achieved by moving either the __________ or __________ .

6. Three hole-making operations which can be performed on a milling machine are __________ , __________ and __________ .

7. Three special operations which can be performed on a milling machine are __________ , __________ and __________ .

8. List four factors to consider when specifying a milling machine.

    a.

    b.

    c.

    d.

Identify the parts of the milling machine shown in the figure.

9.

10.

11.

12.

13.

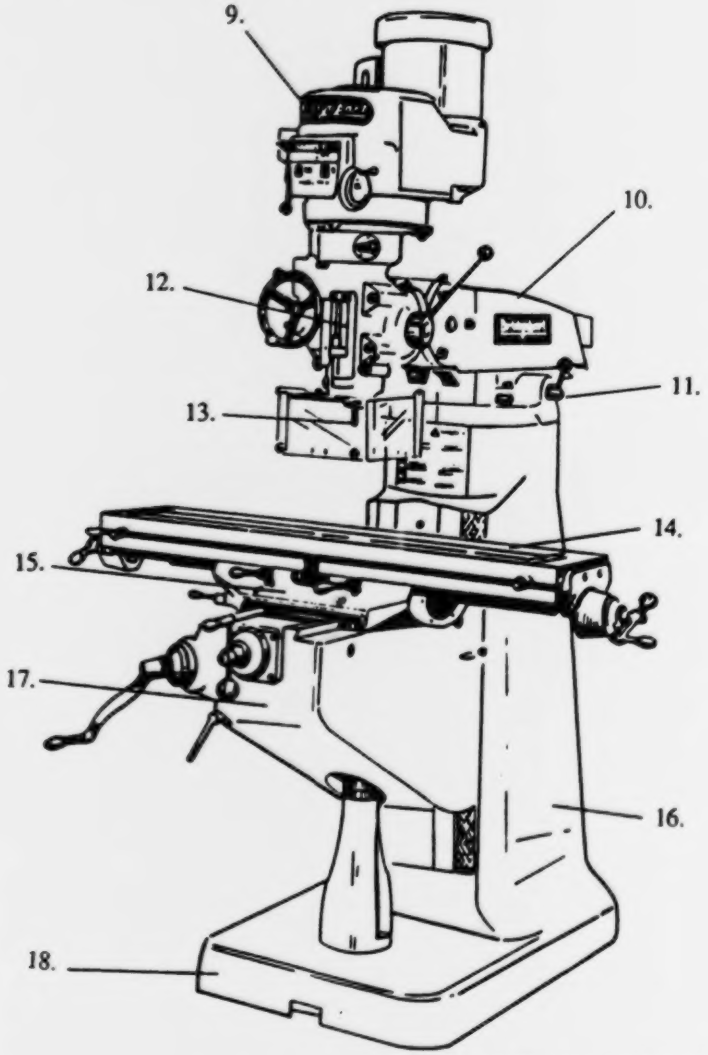
14.

15.

16.

17.

18.


9.
10.
12.
11.
13.
14.
15.
17.
16.
18.

Credit: Bridgeport Machines, Inc.

ANSWERS TO AS 1.1

1. Stationary
2. Vertical, horizontal
3. Knee, column
4. Precision jig borer or jig borer
5. Knee, quill
6. Drilling, reaming, boring
7. Gear cutting, indexing, radius cutting
8. Type, horsepower, model, capacity
9. Head
10. Ram
11. Turret
12. Quill
13. Spindle
14. Table
15. Saddle
16. Column
17. Knee
18. Base

MODULE: MILLING

UNIT I: INTRODUCTION

UNIT TEST

Identify the milling machine parts shown in the illustration.

____ 1.

____ 2.

____ 3.

____ 4.

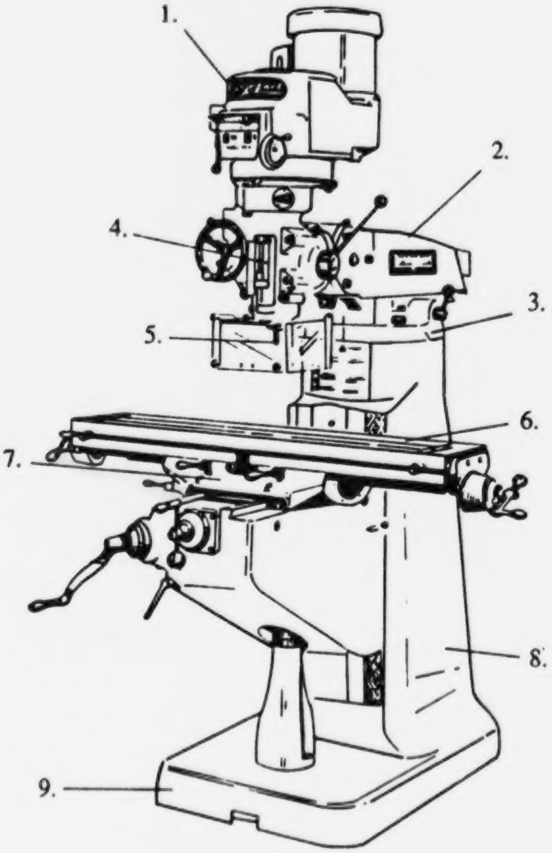
____ 5.

____ 6.

____ 7.

____ 8.

____ 9.



Credit: Bridgeport Machines, Inc.

a. Base
b. Column
c. Head
d. Knee
e. Quill
ab. Ram
ac. Saddle
ad. Spindle
ae. Table
bc. Turret

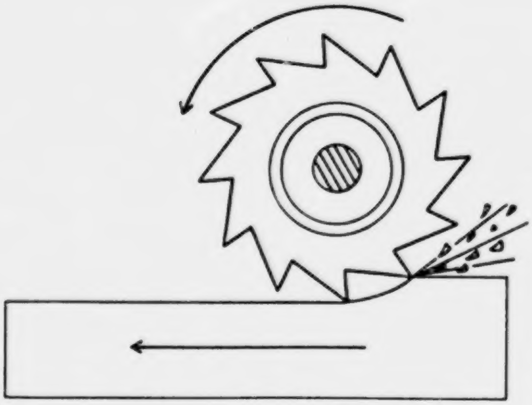
Select the option which best answers the question or completes the statement.

____ 10. What type of machine is the one shown in the previous illustration?

a. Horizontal, knee and column
b. Vertical, knee and column
c. Horizontal, bed
d. Horizontal, computerized
e. Vertical, bed

____ 11. Identify the process illustrated below.

- a. Gear cutting
- b. Milling
- c. Drilling
- d. Reaming
- e. Grinding



____ 12. Which term indicates the output power of a milling machine spindle drive motor?

- a. Type
- b. Model
- c. Horsepower
- d. Capacity
- e. Speed

____ 13. Which word describes the total amount of travel of a milling machine table?

- a. Capacity
- b. Horsepower
- c. Model
- d. Longitudinal
- e. rpm

____ 14. Which is not an example of a hole-making operation which can be performed on a milling machine?

- a. Drilling
- b. Gear cutting
- c. Reaming
- d. Boring
- e. Counterboring

Match the name of the milling machine part with the type of motion it can achieve. (Answers may be used more than once.)

____ 15.	Saddle	a.	Rotation
____ 16.	Table	b.	Transverse
____ 17.	Quill	c.	Longitudinal
____ 18.	Spindle	d.	Vertical
____ 19.	Knee		

ANSWERS TO UNIT TEST

1. c
2. ab
3. bc
4. e
5. ad
6. ae
7. ac
8. b
9. d
10. b
11. b
12. c
13. a
14. b
15. b
16. c
17. d
18. a
19. d

MODULE: MILLING
UNIT II: STRUCTURE AND ACCESSORIES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to identify and describe the function of vertical and horizontal milling equipment parts and accessories. This knowledge will be evidenced by achieving a specified score on the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match terms and definitions related to milling machine structure and parts.

1.2 Identify parts of a vertical milling machine.

1.3 Identify parts of a horizontal milling machine.

2.1 Match terms and definitions about milling machine accessories.

2.2 Identify accessories for holding work.

2.3 Identify accessories for holding cutting tools.

2.4 Identify special milling machine accessories.

MODULE: MILLING

UNIT II: STRUCTURE AND ACCESSORIES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: DETAILED MACHINE STRUCTURE AND PARTS

a. Information outline

b. Transparency masters

TM 1.1: Drawbar in vertical milling head
TM 1.2: T-slots
TM 1.3: Graduated micrometer dial

c. Assignment sheet

AS 1.1: Milling machine parts

d. Answers to assignment sheet

2. Lesson 2: MILLING ACCESSORIES

a. Information outline

b. Handouts

HO 2.1: Work-holding devices
HO 2.2: Tool holders

c. Assignment sheet

AS 2.1: Milling machine accessories

d. Answers to assignment sheet

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guide

1. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

MODULE: MILLING

UNIT II: STRUCTURE AND ACCESSORIES

LESSON 1: DETAILED MACHINE STRUCTURE AND PARTS

I. Terms and definitions **(TM 1.1-1.3)**

A. Drawbar--threading that extends through the center of the milling machine spindle and which draws and tightens spring collets

B. Spindle--precision cylinder which turns and holds cutting tool

C. Quill--precision cylinder which can move vertically in the milling head. It contains the spindle and spindle bearings.

D. T-slots--T-shaped slots in the milling table used for clamping fixtures and work to the table

E. Micrometer dials--graduated dials which permit accurate positioning of the table

F. High/neutral/low selector--lever which permits a change into back gear for speed reduction

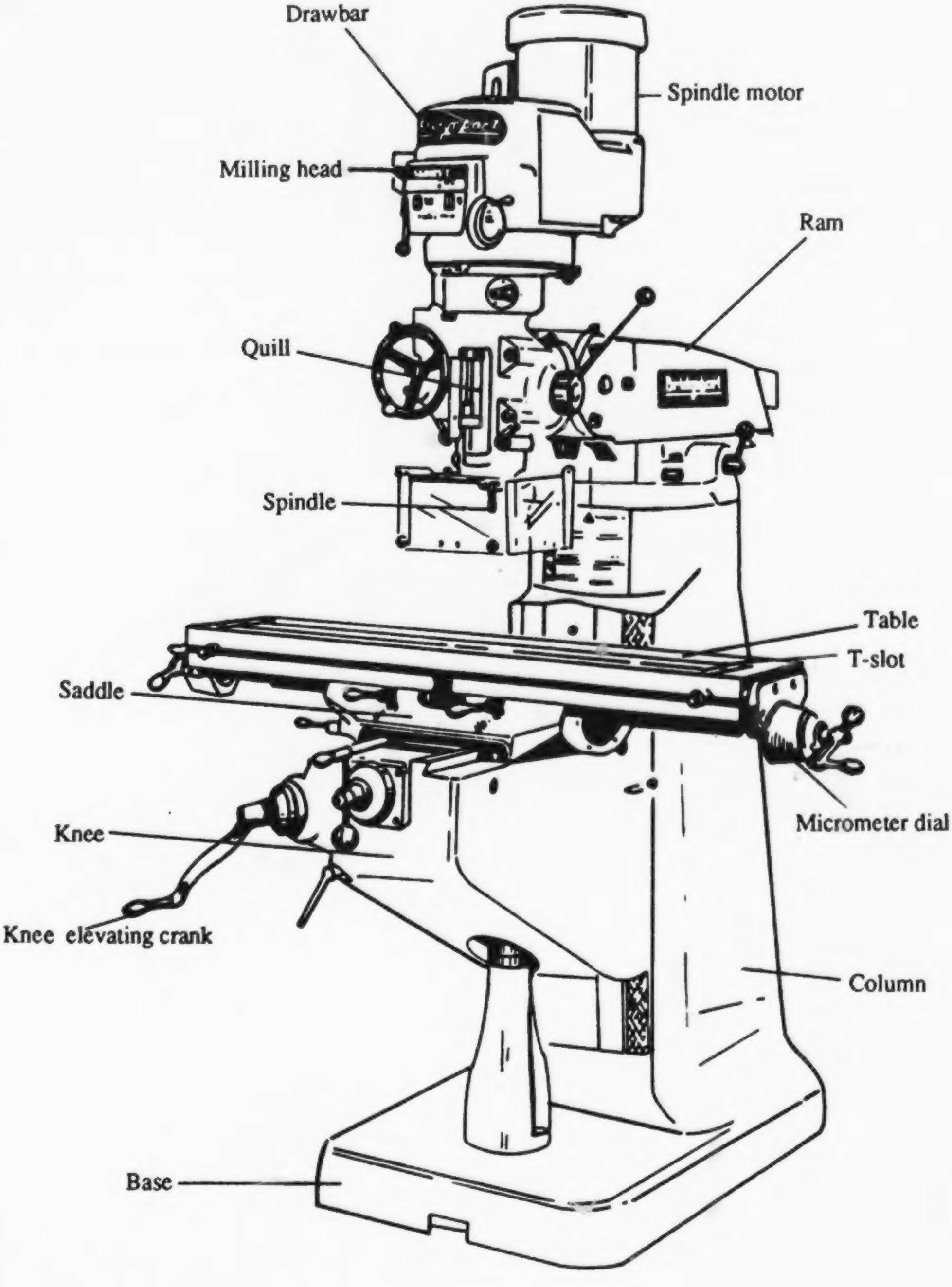
G. Micrometer adjusting nut--nut on the face of the milling head which can be adjusted as a precision depth stop for the quill

H. Overarm--a large casting extending across the milling table from the top of a horizontal milling machine to suspend and position the arbor support

I. Arbor support--a casting containing a bearing which supports the end of a milling arbor on a horizontal milling machine

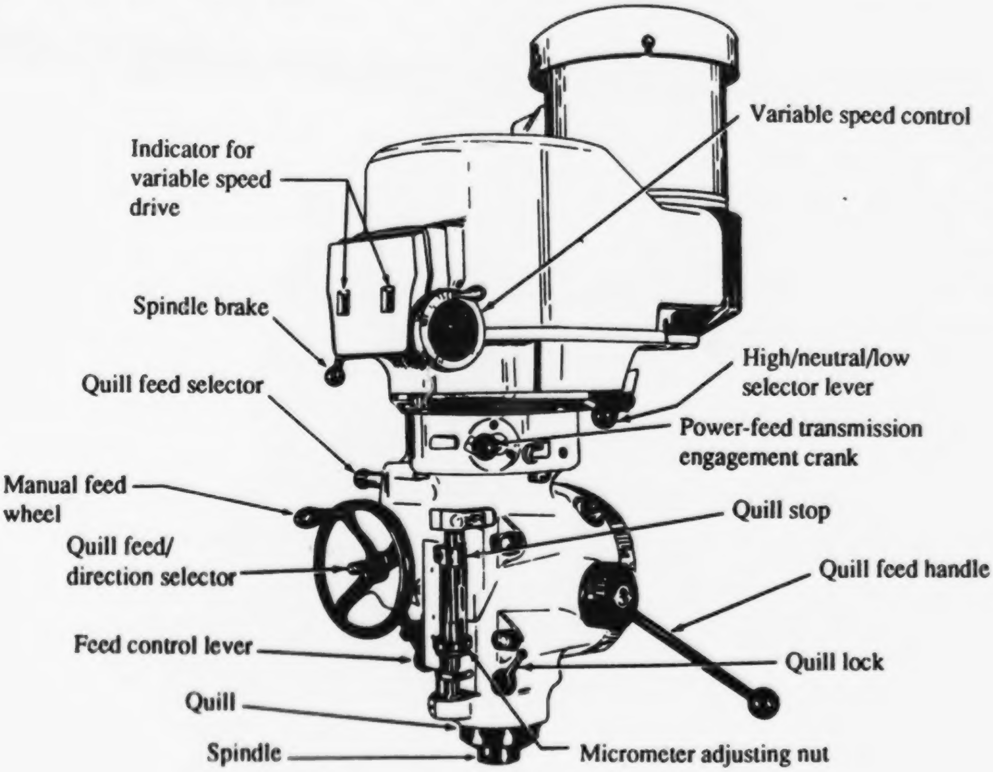
II. Vertical milling machine structure

A. Major components


Drawbar
Spindle motor
Milling head
Ram
Quill
Spindle
Table
T-slot
Saddle
Micrometer dial
Knee
Knee elevating crank
Column
Base

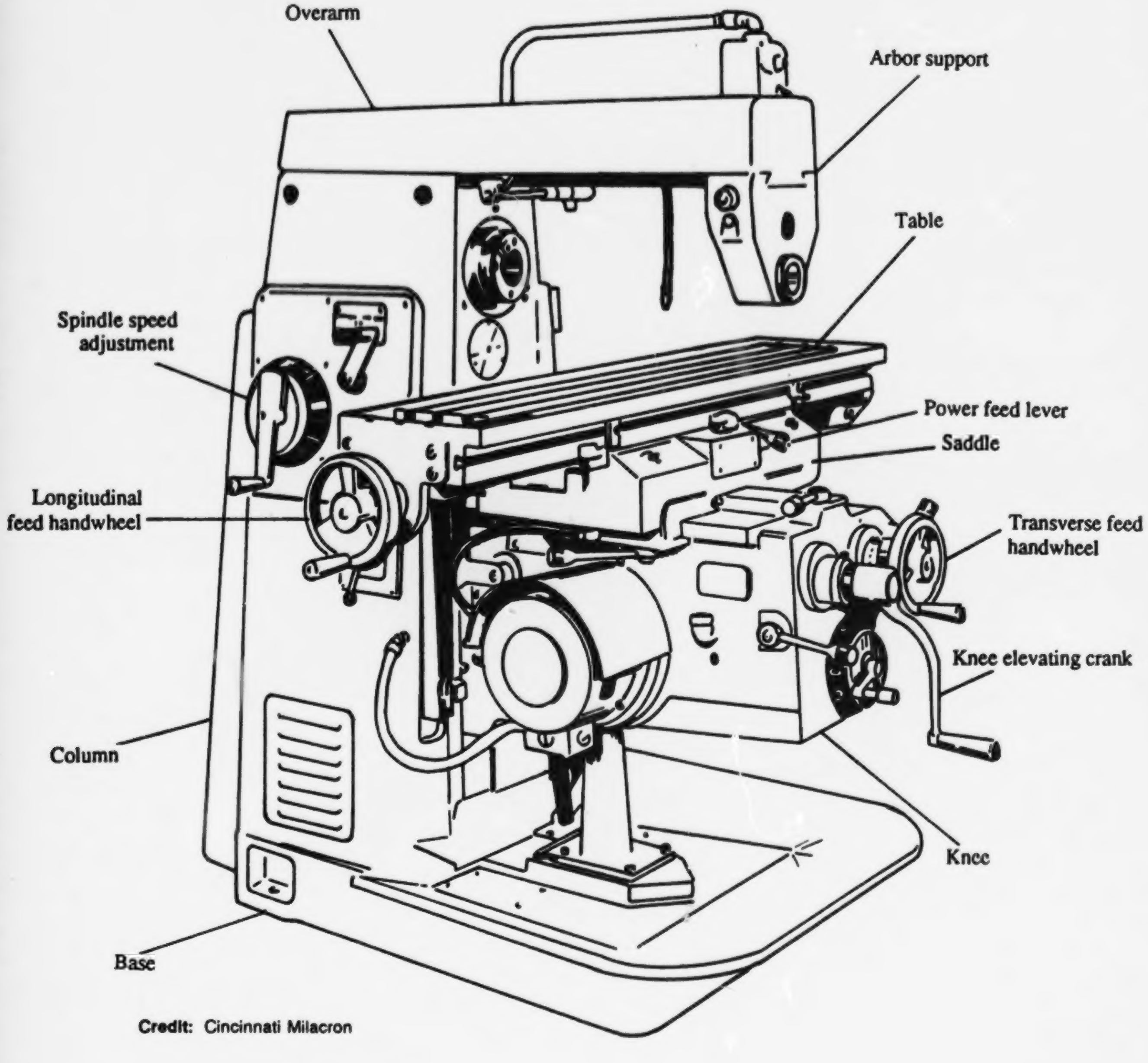
Credit: Bridgeport Machines, Inc.

B. Milling head components


Variable speed control
Indicator for variable speed drive
Spindle brake
High/neutral/low selector lever
Quill feed selector
Power-feed transmission engagement crank
Manual feed wheel
Quill stop
Quill feed/ direction selector
Quill feed handle
Feed control lever
Quill lock
Quill
Spindle
Micrometer adjusting nut

Credit: Bridgeport Machines, Inc.

III. Horizontal milling machine structure


Overarm
Arbor support
Table
Spindle speed adjustment
Power feed lever
Saddle
Longitudinal feed handwheel
Transverse feed handwheel
Knee elevating crank
Column
Knee
Base

Credit: Cincinnati Milacron

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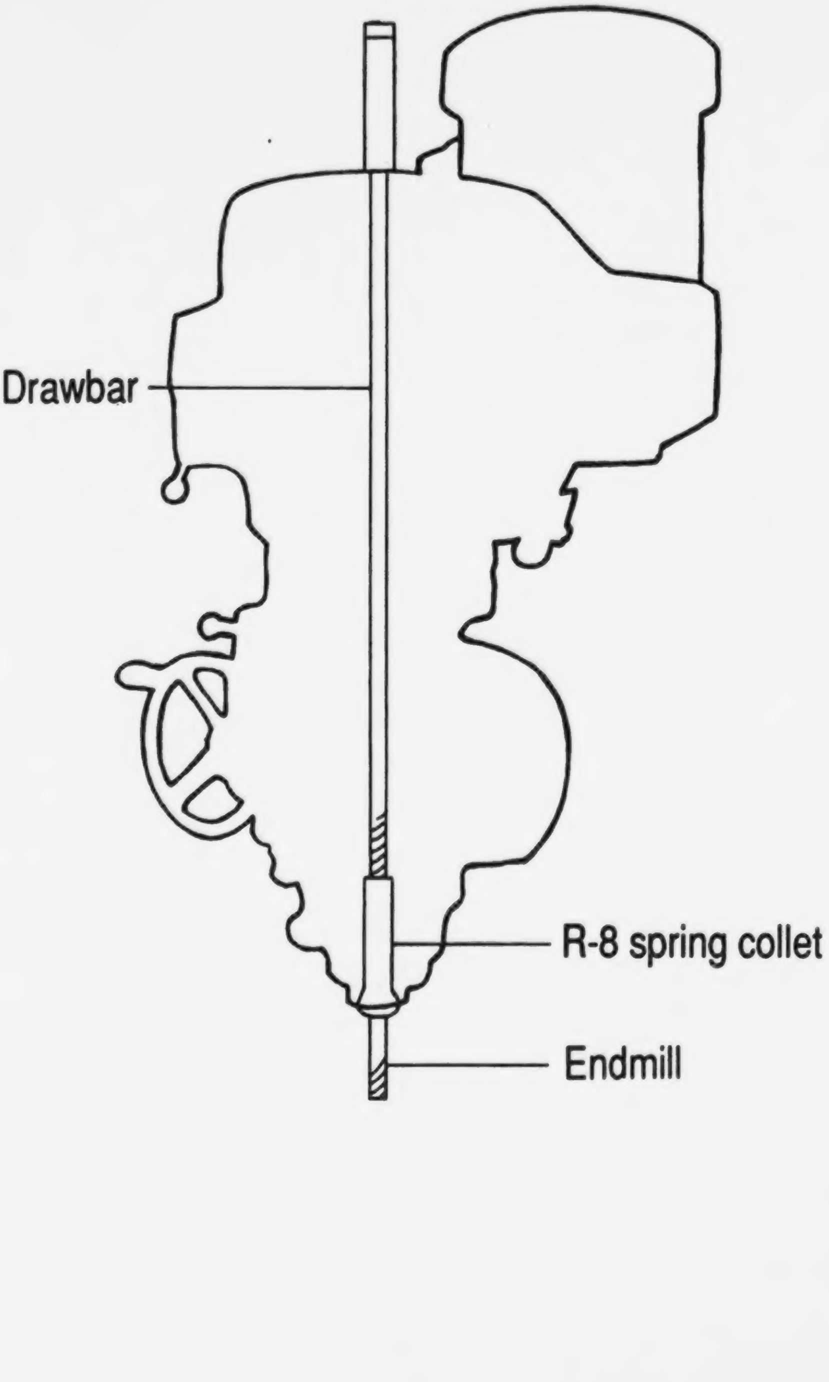
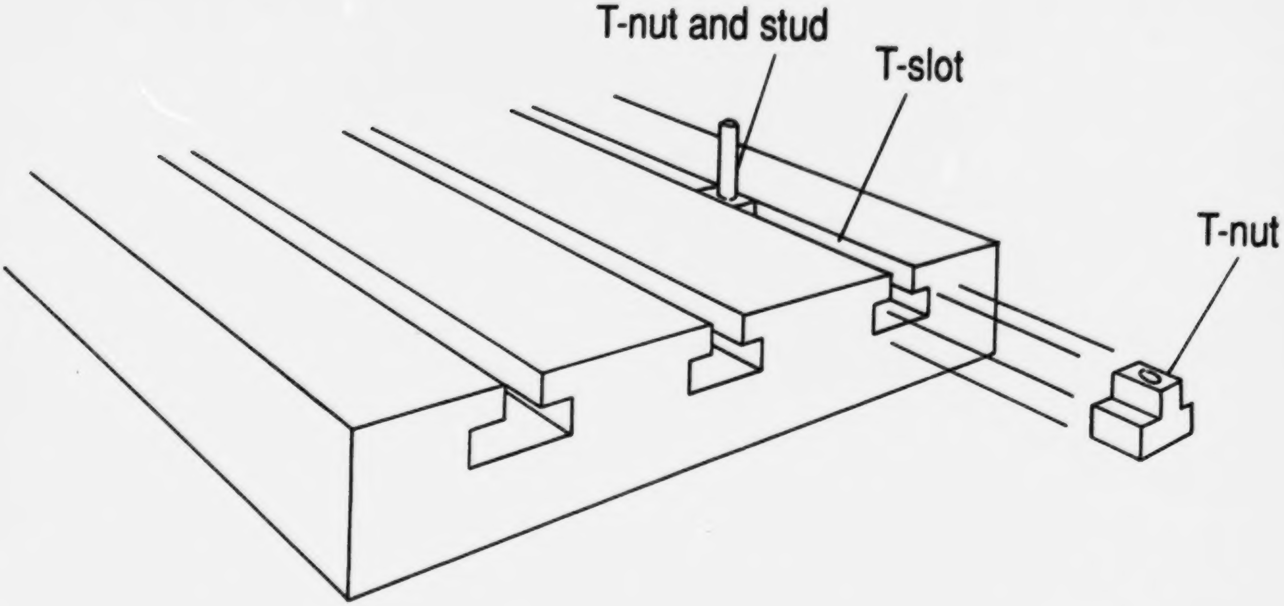
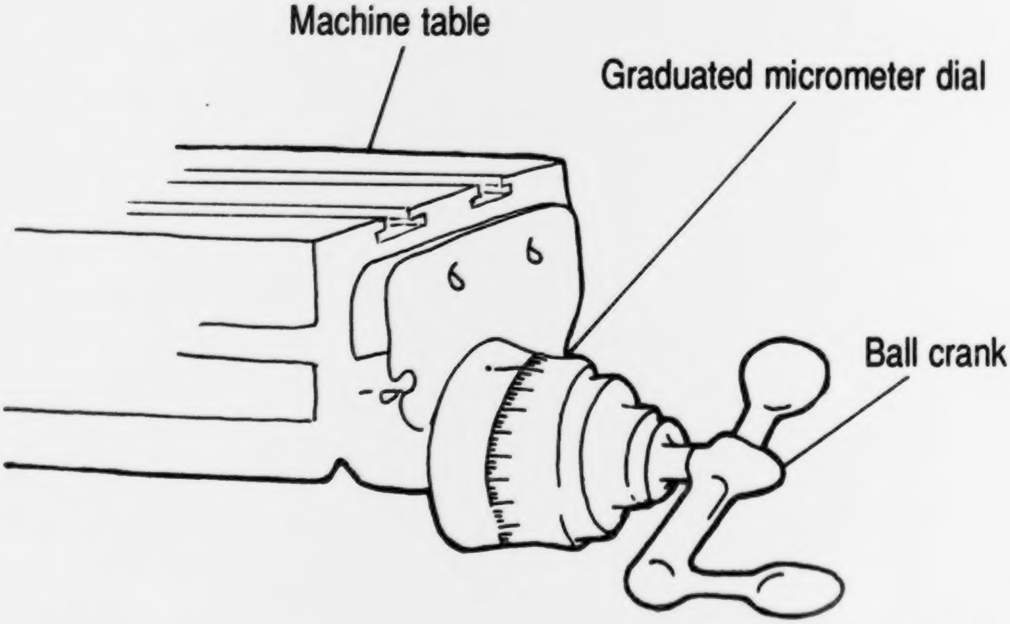
DRAWBAR IN VERTICAL MILLING HEAD


Drawbar
R-8 spring collet
Endmill

T-SLOTS


T-nut and stud
T-slot
T-nut

GRADUATED MICROMETER DIAL


Machine table
Graduated micrometer dial
Ball crank

MILLING MACHINE PARTS

I. Identify the parts of the vertical milling machine.

A.

B.

C.

D.

E.

F.

G.

H.

I.

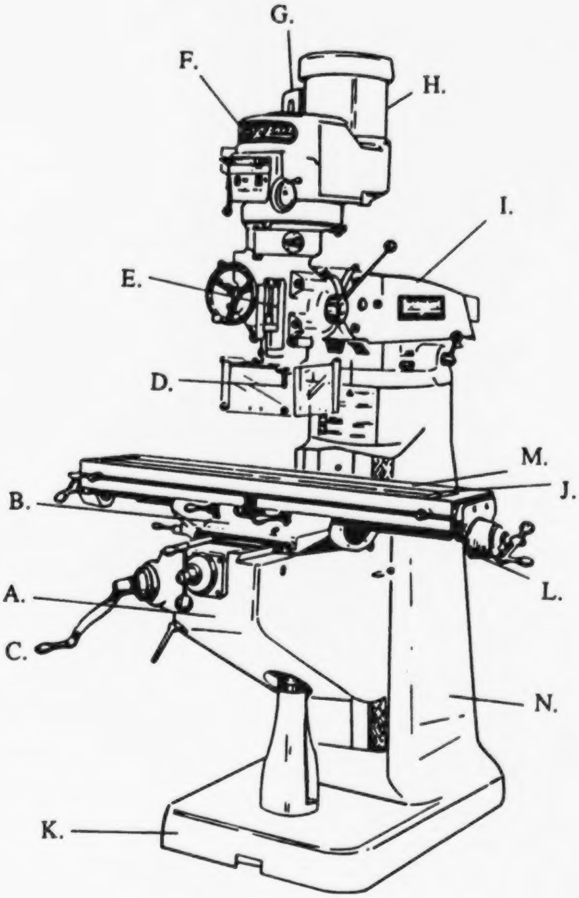
J.

K.

L.

M.

N.


G.
F.
H.
I.
E.
D.
M.
J.
B.
L.
A.
C.
N.
K.

Credit: Bridgeport Machines, Inc.

II. Identify the parts of the vertical milling head.

A.

B.

C.

D.

E.

F.

G.

H.

I.

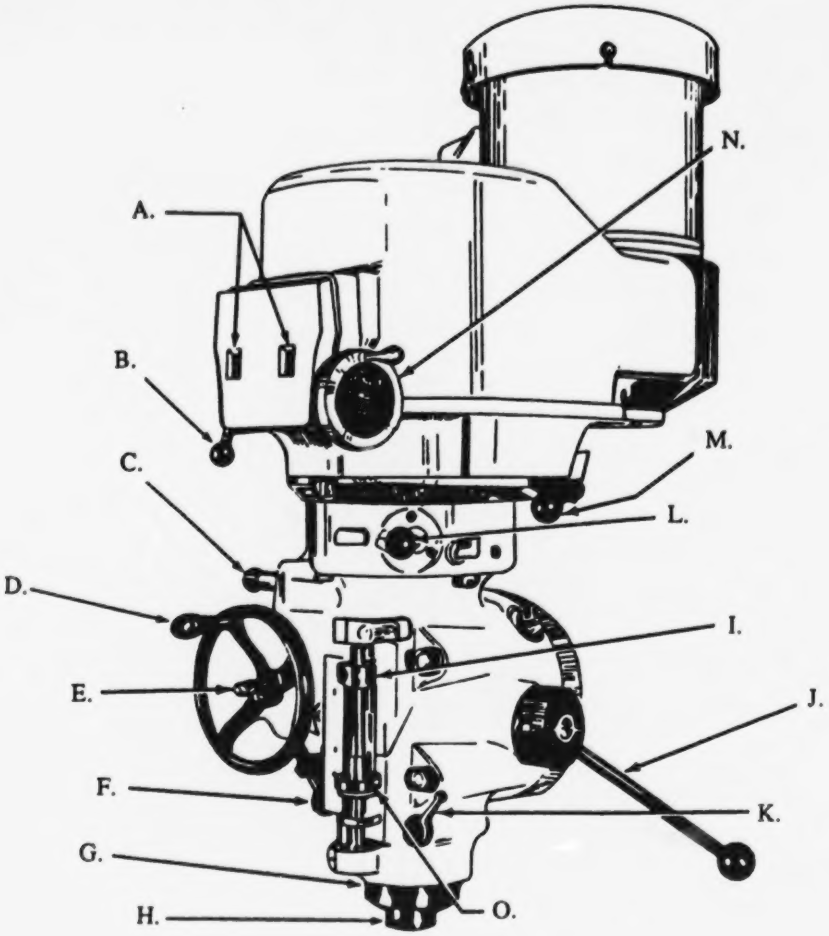
J.

K.

L.

M.

N.


A.
B.
C.
D.
E.
F.
G.
H.
I.
J.
K.
L.
M.
N.
O.

Credit: Bridgeport Machines, Inc.

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III. **Identify the parts of the horizontal milling machine.**

A.

B.

C.

D.

E.

F.

G.

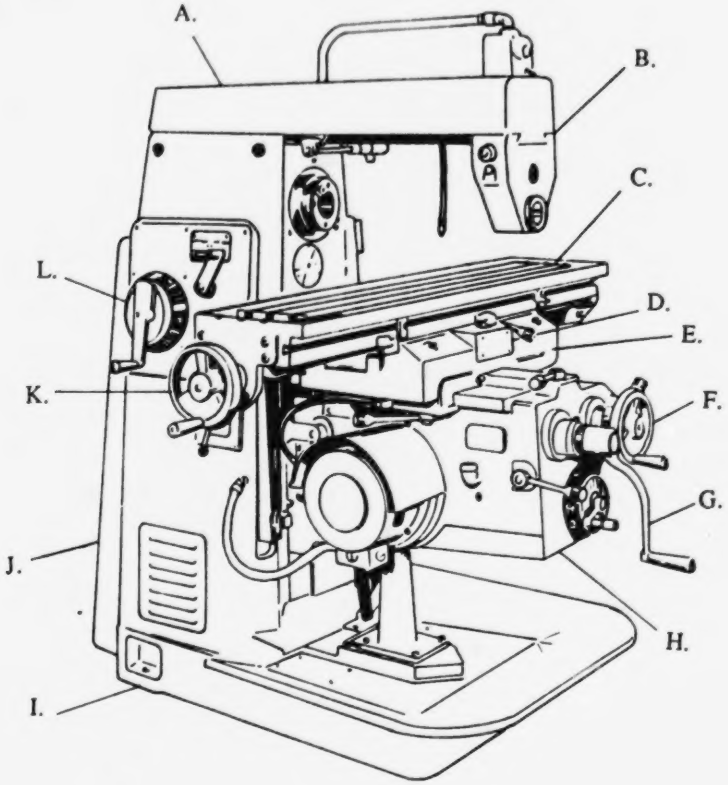
H.

I.

J.

K.

L.


A.
B.
C.
D.
E.
F.
G.
H.
I.
J.
K.
L.

Credit: Cincinnati Milacron

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ANSWERS TO AS 1.1

I. A. Knee
B. Saddle
C. Knee-elevating crank
D. Spindle
E. Quill
F. Milling head
G. Drawbar
H. Spindle motor
I. Ram
J. T-slots
K. Base
L. Micrometer dials
M. Table
N. Column

II. A. Variable-speed dial
B. Spindle brake
C. Quill feed selector
D. Manual-feed wheel
E. Quill feed/direction selector
F. Feed-control lever
G. Quill
H. Spindle
I. Quill stop
J. Quill feed handle
K. Quill lock
L. Power-feed transmission engagement
M. High/neutral/low selector
N. Variable-speed control
O. Micrometer adjusting nut

III. A. Overarm
B. Arbor support
C. Table
D. Power-feed lever
E. Saddle
F. Transverse-feed handwheel
G. Knee-elevating crank
H. Knee
I. Base
J. Column
K. Longitudinal-feed handwheel
L. Spindle-speed adjustment

MODULE: MILLING

UNIT II: STRUCTURE AND ACCESSORIES

LESSON 2: MILLING ACCESSORIES

I. Terms and definitions

   A. Arbor--precision shaft used to hold horizontal milling cutters

   B. Boring head--device used to enlarge holes to very precise dimensions

   C. Clamping kit--set of step blocks, clamps, studs and T-nuts used to mount work to a milling table

   D. Digital readout--electronic device used instead of micrometer dials to read the position of the machine table

   E. Indexing collet holder--simple device used to hold a workpiece for indexing by means of a collet

   F. Indexing head--complex work-holding and positioning device with extensive indexing capability

   G. Fly cutter--tool holder which accepts a single-point lathe toolbit

   H. Horizontal milling attachment--attachment for the vertical milling machine permits it to perform horizontal milling operations

   I. R-8 collet--a spring collet accepted by the spindle taper of most "series I" type vertical milling machines

   J. Rotary table--work-holding and positioning device which can provide a rotary axis and angular measurement on a milling machine

   K. Slotting/shaping attachment--attachment for the vertical milling machine which will permit slotting and shaping operations

II. Accessories for holding work **(HO 2.1)**

   A. Swivel-base milling vise

   B. Angle vise

   C. V-blocks

   D. Rotary table

   E. Indexing collet holder

   F. Dividing head

   G. Clamping kit

   H. Angle block

III. Accessories for holding cutting tools **(HO 2.2)**

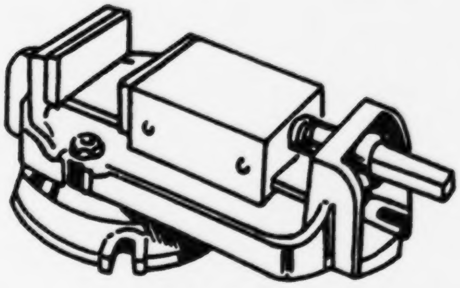
   A. R-8 collets
   B. Fly cutter
   C. Shell end-mill holder
   D. Arbors
   E. Boring head

IV. Special accessories

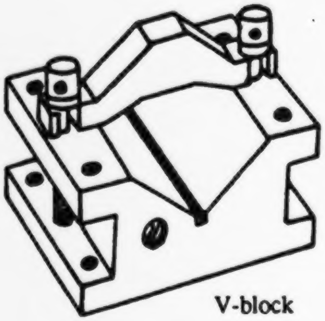
   A. Boring head
   B. Horizontal milling attachment
   C. Slotting/shaping attachment
   D. Digital readout

HO 2.1

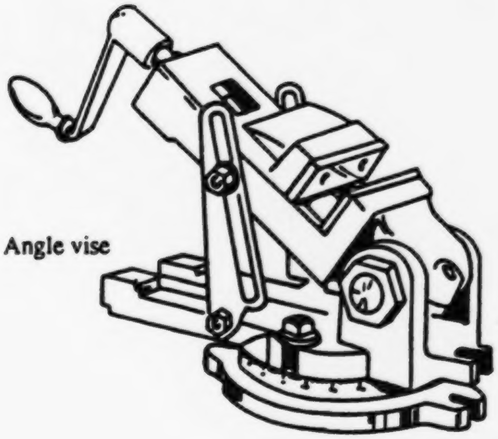
WORK-HOLDING DEVICES



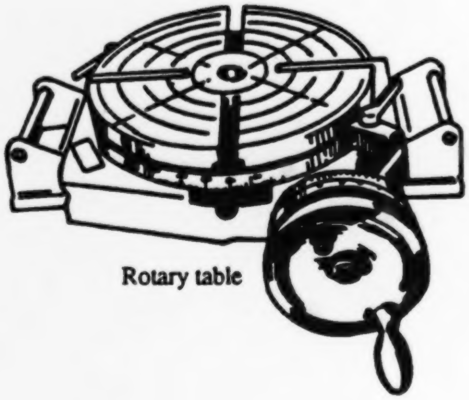
Milling vise



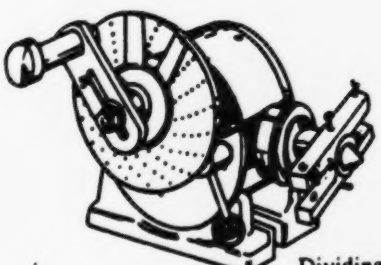
V-block



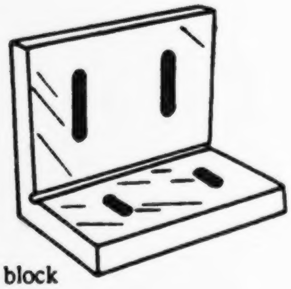
Angle vise



Rotary table

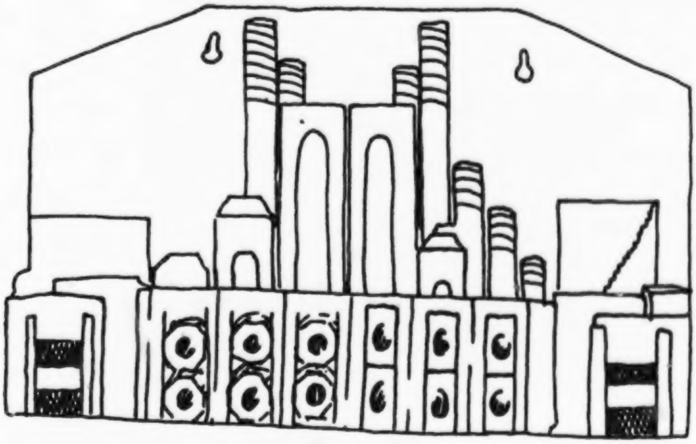


Dividing head

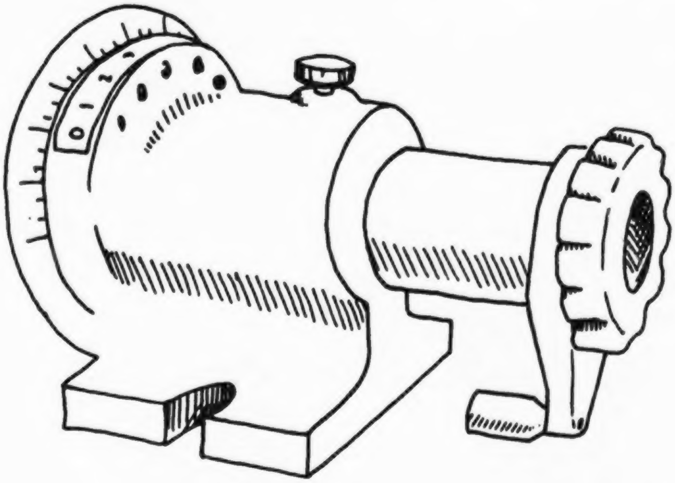


Angle block

Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 14, 15 and 28. Used by permission.



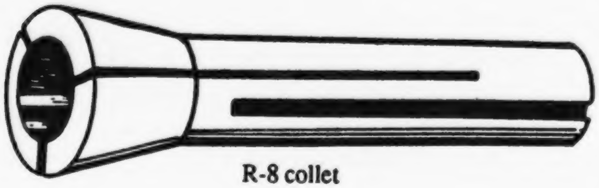
Clamping kit



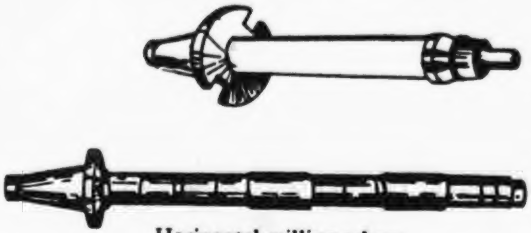
Indexing collet holder

HO 2.2

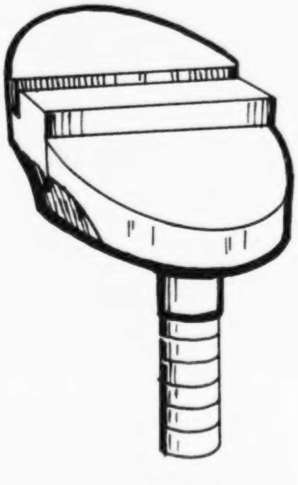
TOOL HOLDERS



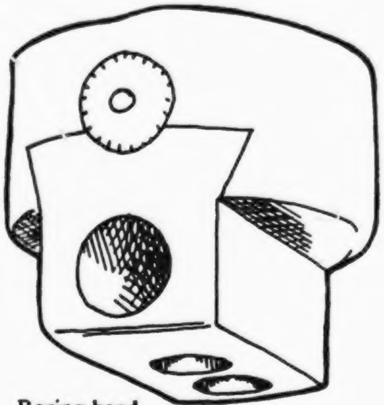
R-8 collet



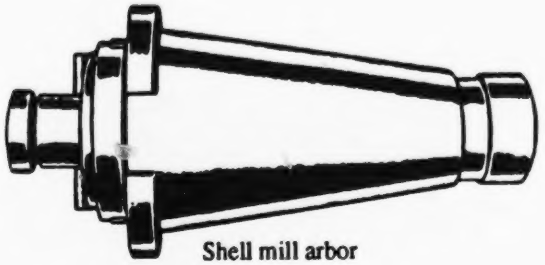
Horizontal milling arbors



Fly cutter



Boring head



Shell mill arbor

Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 24-25. Used by permission.

AS 2.1

MILLING MACHINE ACCESSORIES

Identify the milling machine accessories in the illustrations.

A.

B.

C.

D.

E.

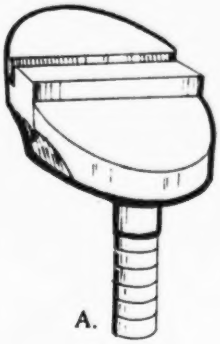
F.

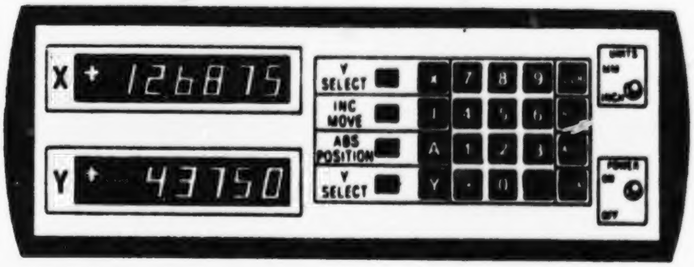
G.

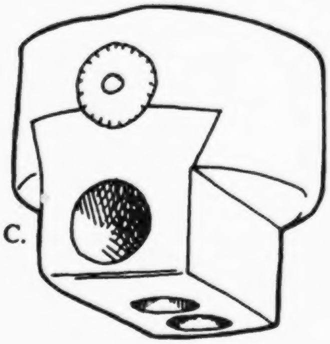
H.

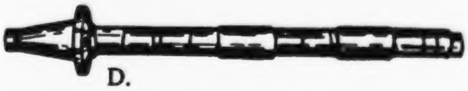
I.

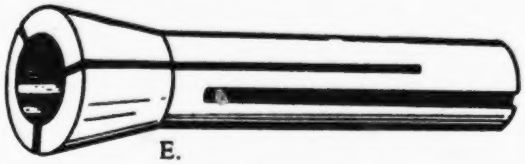
J.

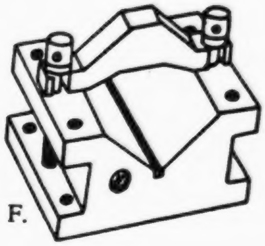

A.

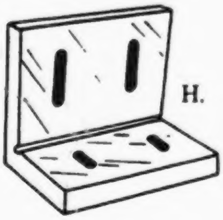

B.
X
+ 126875
Y
+ 43750
SELECT
INC MOVE
ABS POSITION
SELECT
7 8 9
4 5 6
A 1 2 3
Y 0
POWER
ON
OFF

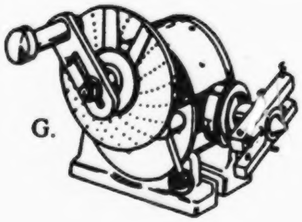

C.

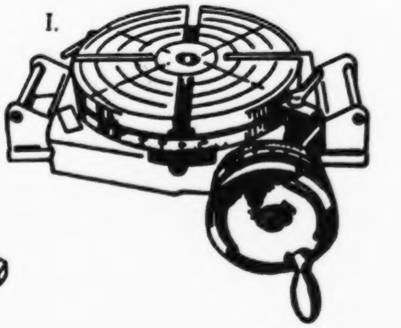

D.

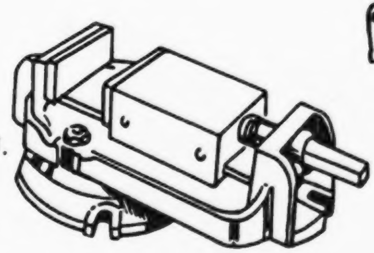

E.


F.


H.


G.


I.


J.

Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 14-16, 24-27. Used by permission.

ANSWERS TO AS 2.1

A. Fly cutter

B. Digital readout

C. Boring head

D. Arbor

E. R-8 collet

F. V-block

G. Dividing head

H. Angle block

I. Rotary table

J. Milling vise

MODULE: MILLING

UNIT II: STRUCTURE AND ACCESSORIES

UNIT TEST

Write the letter of the part shown on the vertical milling machine illustration beside the name of the part in the list below.

____ 1. Drawbar

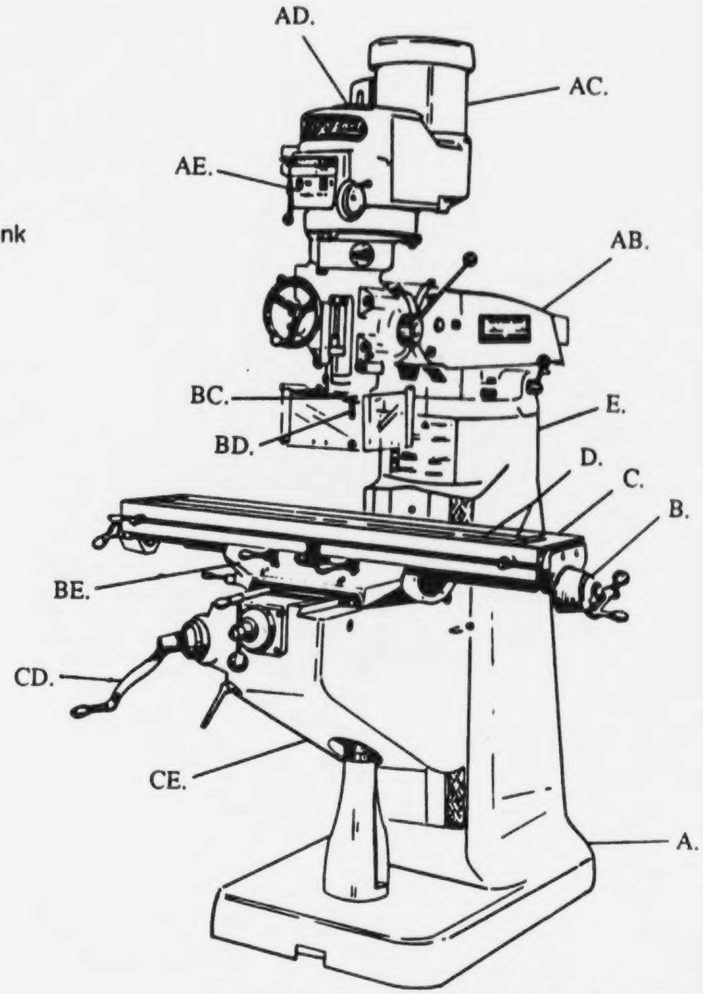
____ 2. Spindle motor

____ 3. Ram

____ 4. Saddle

____ 5. Knee-elevating crank

____ 6. Micrometer dials



Credit: Bridgeport Machines, Inc.

Match the letter of the part shown on the illustration of the milling head to the name of the part in the list below.

___ 7. High/neutral/low selector

___ 8. Manual-feed wheel

___ 9. Micrometer adjusting nut

___ 10. Power-feed transmission engagement

___ 11. Quill lock

___ 12. Quill feed/direction selector

___ 13. Quill feed handle

___ 14. Quill feed selector

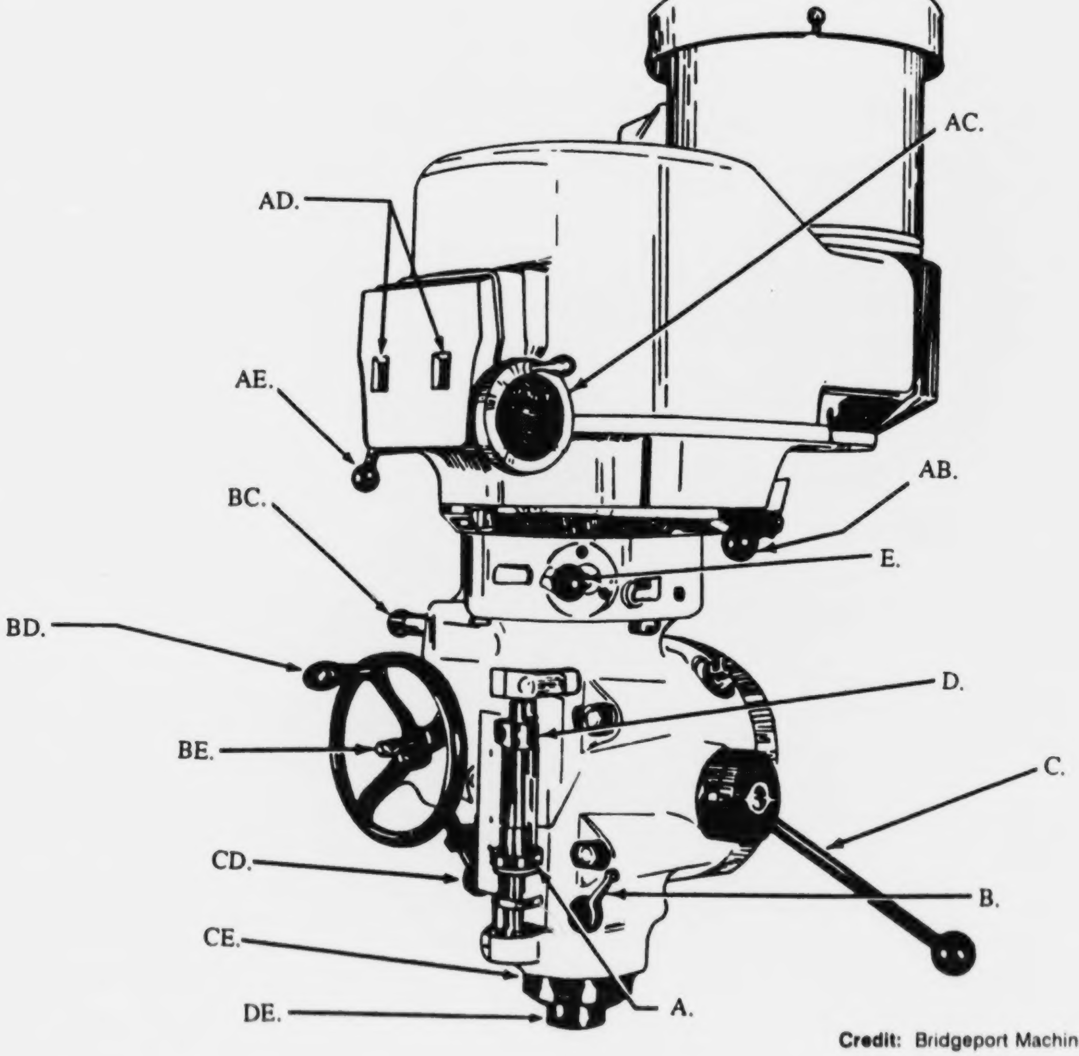
___ 15. Quill stop

___ 16. Spindle

___ 17. Spindle brake

___ 18. Variable-speed control

___ 19. Variable-speed dial



Credit: Bridgeport Machines, Inc

Match the letter of the part shown on the horizontal milling machine illustration to the name of the part in the list below.

____ 20. Arbor support

____ 21. Knee crank

____ 22. Longitudinal-feed handwheel

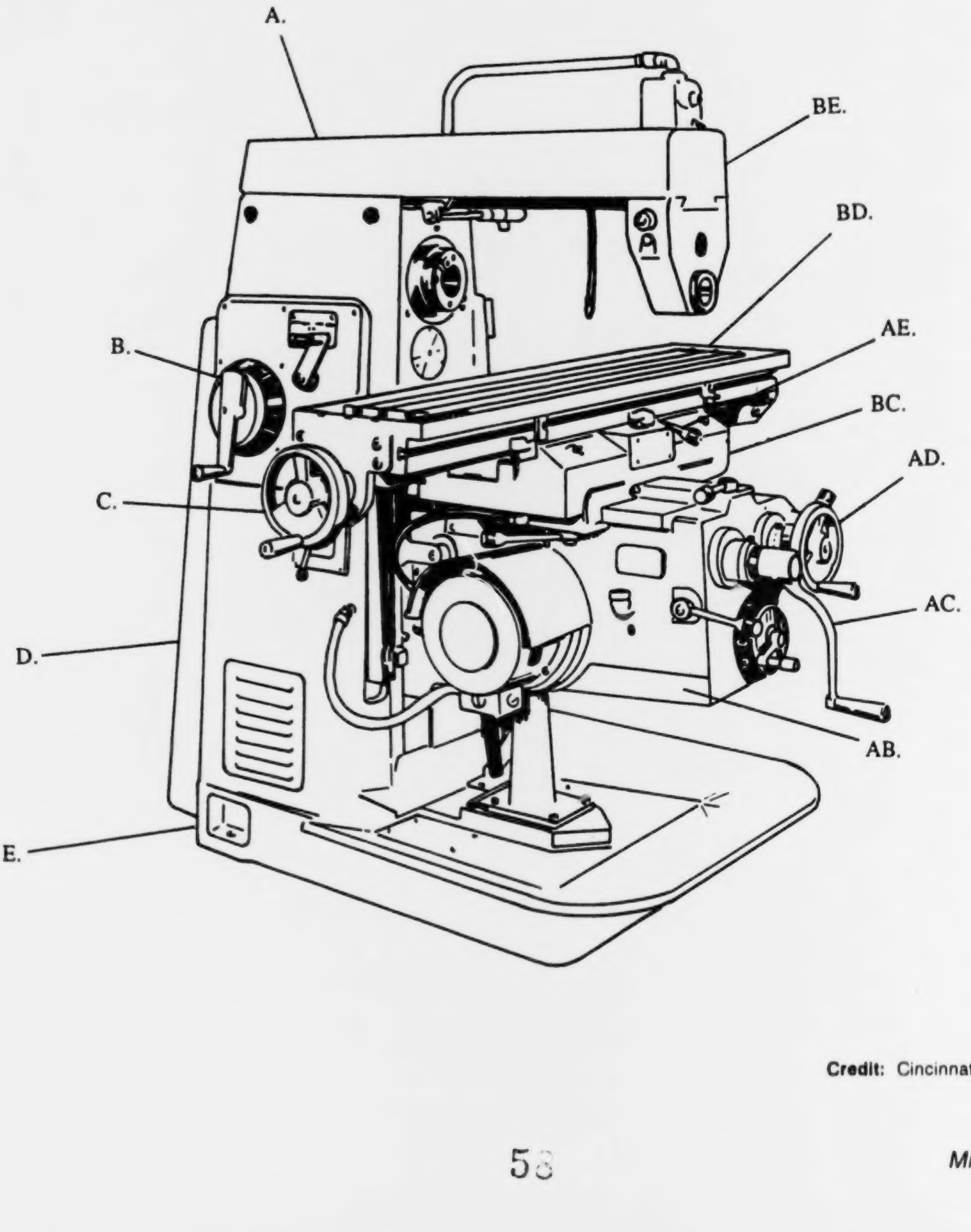
____ 23. Overarm

____ 24. Power-table feed lever

____ 25. Saddle

____ 26. Spindle-speed selector

____ 27. Transverse-feed handwheel



Credit: Cincinnati Milacron

Select the option which best answers the question or completes the statement.

____ 28. Which is a device used to tighten a collet held in a milling machine spindle?

a. Rotary table
b. Arbor
c. Quill
d. Drawbar
e. Overarm

____ 29. This milling machine component can move a cutting tool up and down but does not turn.

a. Spindle
b. Quill
c. Indexing head
d. Collet
e. Drawbar

____ 30. Which feature of a milling machine table permits work to be clamped directly to the table?

a. Indexing head
b. Micrometer dial
c. Arbor support
d. T-slot
e. Ram

____ 31. Which controls quill depth?

a. Micrometer dial
b. Spindle
c. High/neutral/low selector
d. Drawbar
e. Micrometer adjustment nut

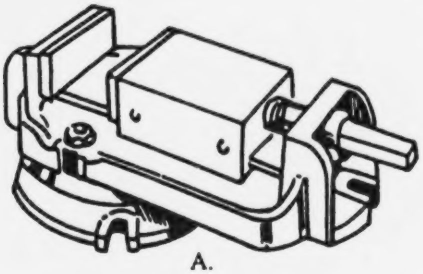
____ 32. Which device is used to enlarge holes with high precision?

a. Boring head
b. Fly cutter
c. Indexing head
d. Rotary table
e. Spindle

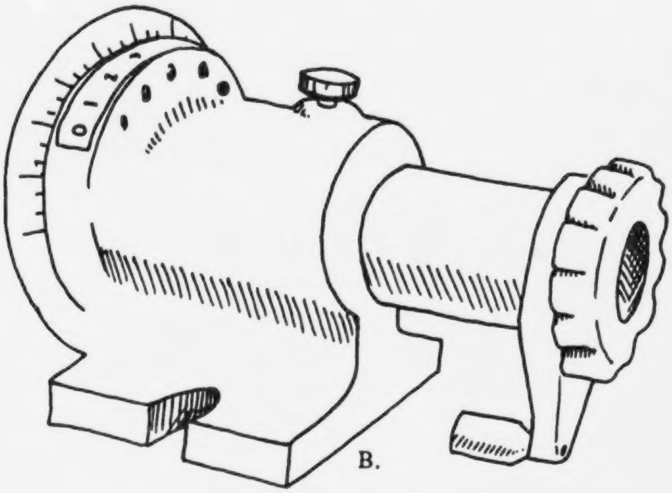
Match the letters of the milling machine accessories shown in the following illustrations with the names of the parts below.

____ 33. Angle vise
____ 34. Boring head
____ 35. Indexing collet holder

____ 36. Indexing head
____ 37. Milling vise
____ 38. R-8 collet
____ 39. Rotary table



A.



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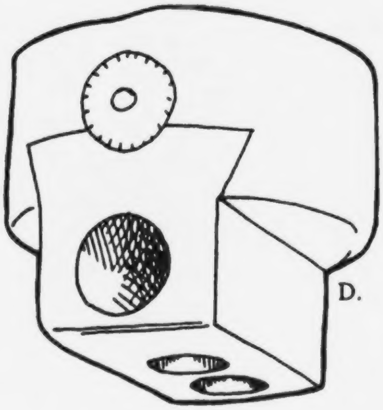

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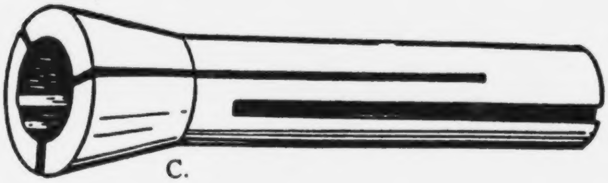

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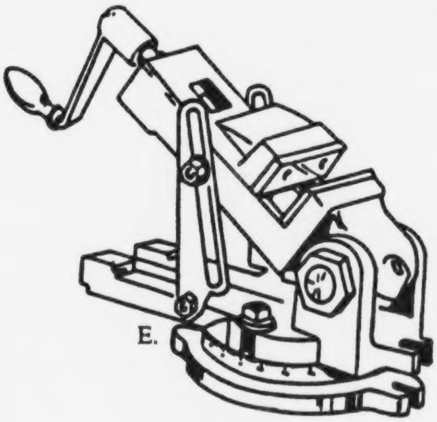
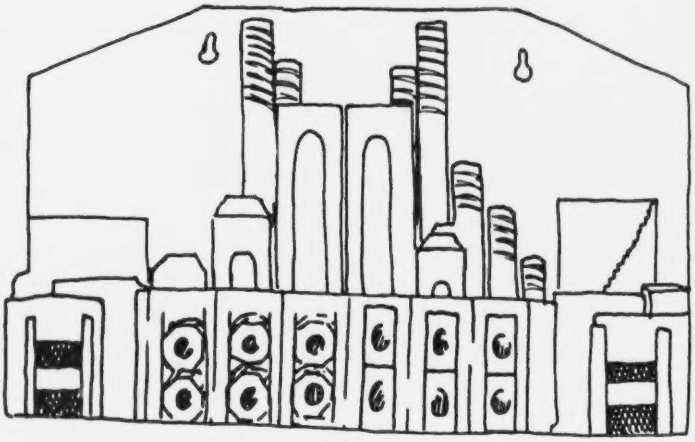
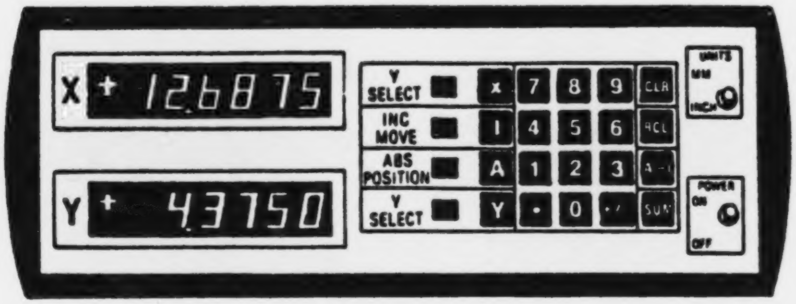


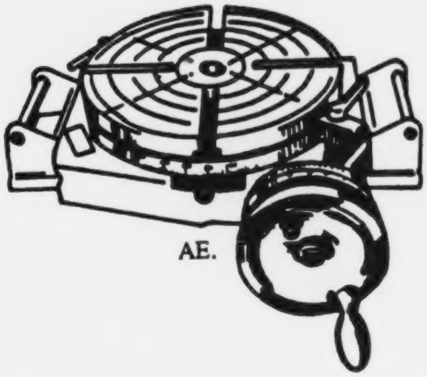
E.



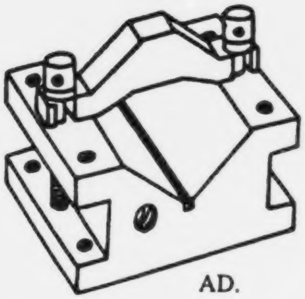
AB.


X
+ 12.6875
Y
+ 4.3750
Y SELECT
INC MOVE
ABS POSITION
Y SELECT
x
7
8
9
CLR
I
4
5
6
RCL
A
1
2
3
Y
•
0
SUM
UNITS
MM
INCH
POWER
ON
OFF

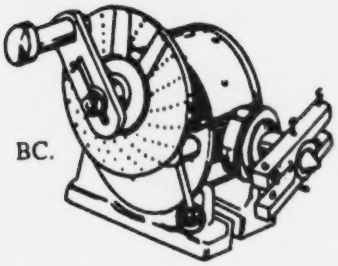
AC.



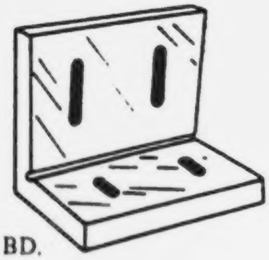
AE.



AD.



BC.



BD.

Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 14-16, 24-27. Used by permission.

ANSWERS TO UNIT TEST

1. ad
2. ac
3. ab
4. be
5. cd
6. b
7. ab
8. bd
9. a
10. e
11. b
12. be
13. c
14. bc
15. d
16. de
17. ae
18. ac
19. ad
20. be
21. ac
22. c
23. a
24. ae
25. bc
26. b
27. ad
28. d
29. b
30. d
31. e
32. a
33. e
34. d
35. b
36. bc
37. a
38. c
39. ae

MODULE: MILLING

UNIT III: SAFETY AND MAINTENANCE

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to follow guidelines for the safe operation of milling machines and should be able to clean and lubricate vertical milling machines. This knowledge will be evidenced by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify general rules for personal safety when working with milling machines.

1.2 Identify specific rules for milling machine safety. (competency J1)

2.1 Match terms and definitions related to milling machine lubrication and maintenance.

2.2 Clean and lubricate a vertical milling machine. (competency J2, JS 2.1)

MODULE: MILLING

UNIT III: SAFETY AND MAINTENANCE

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

  1. Lesson 1: SAFETY GUIDELINES

    a. Information outline

    b. Transparency masters

      TM 1.1: Removing chips
      TM 1.2: Removing chips (cont.)

  2. Lesson 2: LUBRICATION AND MAINTENANCE

    a. Information outline

    b. Transparency masters

      TM 2.1: T-slot cleaner
      TM 2.2: Machine lubrication

    c. Job sheet

      JS 2.1: Clean and lubricate a vertical milling machine

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

  1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

  2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

  3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guide

1. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.
2. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

MODULE: MILLING

UNIT III: SAFETY AND MAINTENANCE

LESSON 1: SAFETY GUIDELINES

I. General guidelines **(TM 1.1, 1.2)**

   A. Use rags when handling sharp cutters to avoid injury.

   B. Make sure that the workpiece is held securely to prevent slippage when a cutting force is applied.

   C. Know the location and function of all machine controls. Never let another person operate the controls for you.

   D. Do not lean on the machine.

   E. Never use a machine which has a warning tag attached.

   F. Never remove chips with bare hands. Use a brush or rag.

   G. Never use compressed air to clean a machine since this can force chips between machine surfaces and cause injury to personnel.

   H. Keep the work area clean at all times.

   I. Ask for assistance or use a hoist for heavy objects such as vises.

   J. Make sure that all safety guards are in place.

   K. Wear close-fitting clothing with shirttails tucked in and sleeves rolled up above the elbow.

   L. Wear safety glasses with side shields at all times.

II. Specific safety guidelines

   A. Make sure that cutting tools are held securely to prevent slippage.

   B. Use the correct feed rate adjustment to prevent damage to the cutter and workpiece.

   C. Use the correct cutter rotation (rpm) to prevent damage.

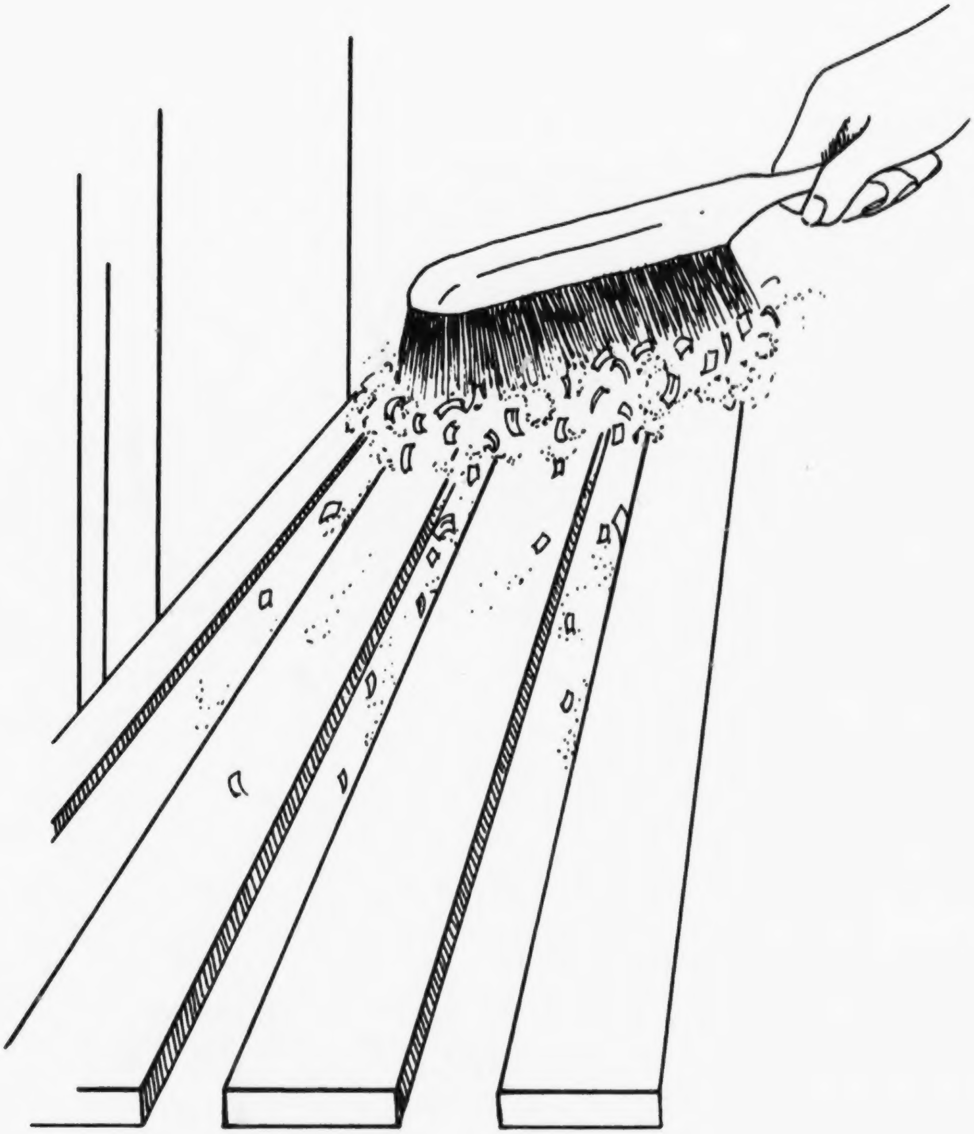
   D. Stop cutter rotation before adjusting the machine or taking measurements.

   E. Before changing the workpiece, move the cutting tool as far away from the workpiece as possible.

   F. Never touch a revolving cutter with the hands.

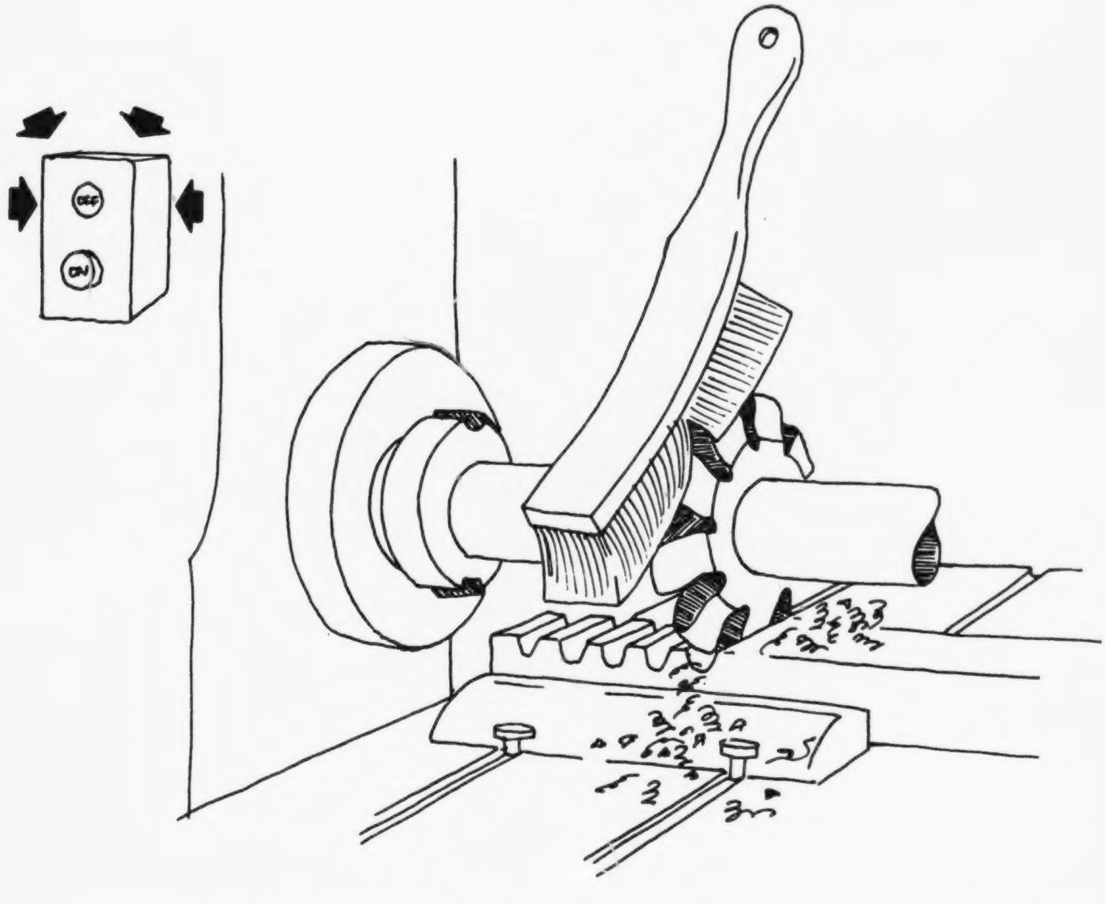
   G. Stay within reach of the stop button while the machine is running.

REMOVING CHIPS



Always use a brush to remove chips from the milling machine.

REMOVING CHIPS (CONT.)



CAUTION: Remove chips **only** when machine is turned off.

MODULE: MILLING

UNIT III: SAFETY AND MAINTENANCE

LESSON 2: LUBRICATION AND MAINTENANCE

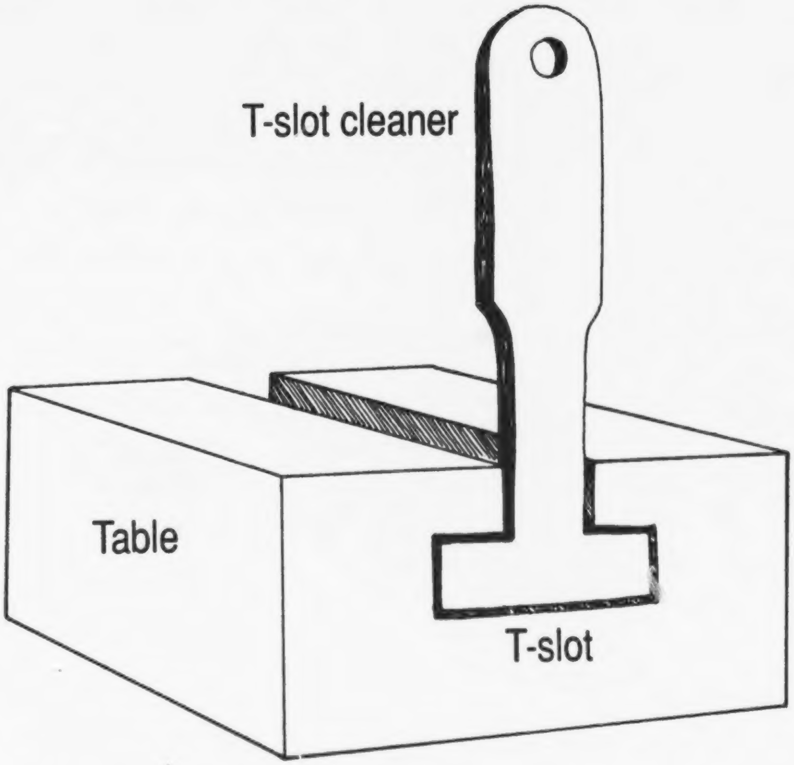
I. Terms and definitions **(TM 2.1, 2.2)**

- A. Grease fitting--protruding feature which will accept the tip of a grease gun to permit application of lubricants under pressure
- B. Oil cup--small reservoir which feeds oil to strategic locations on a machine tool which can not easily be reached
- C. T-slot cleaner--flat T-shaped tool used to remove chips from the T-slots of machine tool tables
- D. Ways--machined precision surfaces on which machine parts move

II. Routine maintenance and lubrication

- A. Cleaning
    1. Turn the machine off.
    2. Remove the cutting tools and set-up accessories.
    3. Brush off the chips.
    4. Use the T-slot cleaner to remove chips from the T-slots.
    5. Wipe the machine with a rag.
- B. Lubrication
    1. Consult the manufacturer's operating manual.
    2. Assemble the necessary lubricants.
    3. Lubricate as required.
    4. Wipe away excess oil and grease with a rag.

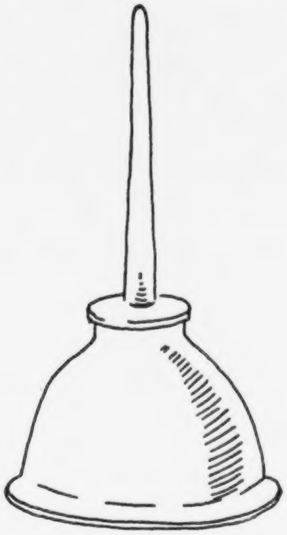
T-SLOT CLEANER

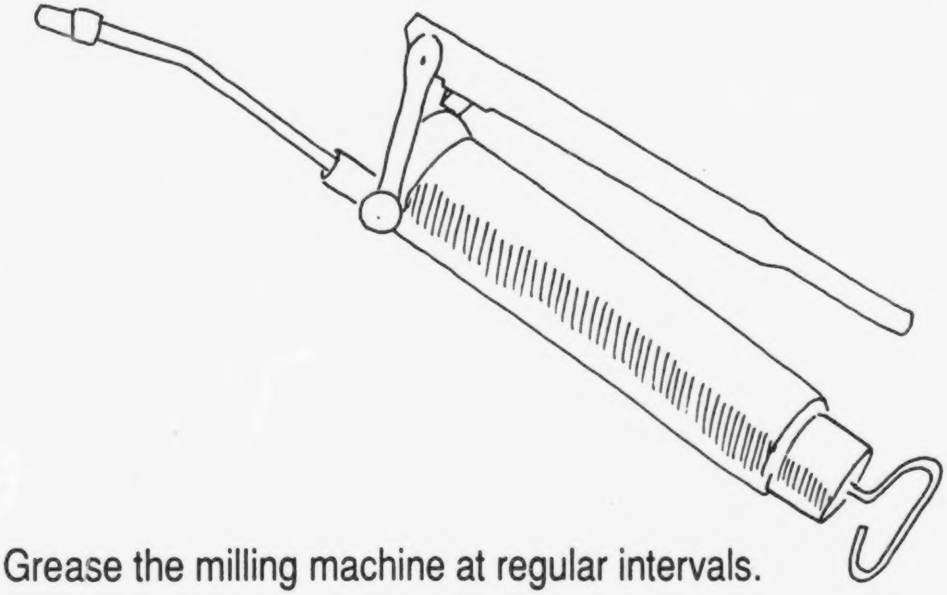

T-slot cleaner
Table
T-slot

Use T-slot cleaner to clean T-slots on tables.

MACHINE LUBRICATION

Oil the milling machine daily.





Grease the milling machine at regular intervals.

JS 2.1

CLEAN AND LUBRICATE A VERTICAL MILLING MACHINE

Equipment:

Operator's manual
Clean rags
Brush
Solvent
Grease gun with recommended way lubricant (waylube)
Pump-type oilers with recommended oils
T-slot cleaner

	Evaluation			
Procedure:	3	2	1	N
1. Make sure that the machine is turned off. Crank the table to its lowest position and remove the cutting tool.	__	__	__	__
2. Crank the cross-feed toward you.	__	__	__	__
3. Brush the chips from the table, vise and T-slots.	__	__	__	__
4. Clean all exposed areas with solvent and a rag. Wipe with a dry rag.	__	__	__	__
5. Crank in the saddle and clean the ways on the front of the knee.	__	__	__	__
6. Crank up the knee and clean the base with a rag and solvent. Wipe dry.	__	__	__	__
7. Consult the operator's manual for the correct lubrication procedure. Lubricate as recommended.	__	__	__	__
NOTE: Many of the newer machines are equipped with one-shot oilers which draw oil from a reservoir on demand.				
8. Wipe off excess oil and grease.	__	__	__	__
9. Clean the work area and put away equipment and materials.	__	__	__	__
Average of above evaluations*	__	__	__	__

*This average is the student's final evaluation for competency J2: Perform care and maintenance (milling machine).

MODULE: MILLING

UNIT III: SAFETY AND MAINTENANCE

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. Which is appropriate to use when handling sharp cutting tools?

a. Rag
b. Tool handler
c. Rubber glove
d. Net
e. None of the above

____ 2. What should be used to remove chips from the milling machine?

a. Compressed air
b. Bare hands
c. Shirt tail
d. Brush
e. None of the above

____ 3. Which of the following can break a tool?

a. Loose holding in the toolholder
b. An excessive feed rate
c. An excessive spindle rpm
d. All of the above
e. None of the above

____ 4. Which is a protruding feature which accepts way lubricant from a gun?

a. Oil cup
b. Machine guard
c. T-slot
d. Grease fitting
e. None of the above

____ 5. What should be on hand before beginning machine cleaning and lubrication?

a. An operator's manual
b. Proper lubricants
c. A brush
d. A T-slot cleaner
e. All of the above

____ 6. Which of the following is a small reservoir which feeds oil to locations on a machine tool?

a. A grease fitting
b. A grease gun
c. A T-slot
d. An oil cup
e. None of the above

____ 7. What should be done before making any adjustments to a machine tool?

a. Set the proper feed rate.
b. Make sure that the cutter has stopped turning.
c. Use compressed air.
d. Remove all chips.
e. None of the above

ANSWERS TO UNIT TEST

1. a (J1)
2. d (J1)
3. d (J1)
4. d (J2)
5. e (J2)
6. d (J2)
7. b (J1)

MODULE: MILLING

UNIT IV: CUTTING-TOOL VARIABLES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to identify various types of cutting tools and applications; determine cutting tool variables; calculate and set correct cutting speeds, spindle rpm and feed rates; and select and apply cutting fluids for milling applications. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match milling machine tool terms with definitions.

1.2 Identify milling machine cutting tools.

2.1 Match speed and rate terms with definitions.

2.2 Calculate cutting speeds and spindle rpm for milling applications. (competencies J6 and J8, JS 2.1)

2.3 Calculate feed rate in inches per minute or meters per minute for milling applications. (competency J6, JS 2.1)

2.4 Identify milling cutting fluid types and applications. (competency J7)

MODULE: MILLING

UNIT IV: CUTTING-TOOL VARIABLES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

   1. Lesson 1: CUTTING-TOOL TYPES

      a. Information outline

      b. Handouts

         HO 1.1: Types of end mills
         HO 1.2: Special form and purpose end mills
         HO 1.3: Arbor-mount milling cutters

      c. Assignment sheet

         AS 1.1: Cutting tool types

      d. Answers to assignment sheet

   2. Lesson 2: MILLING CALCULATIONS AND VARIABLES

      a. Information outline

      b. Handout

         HO 2.1: Feeds and speeds for milling

      c. Assignment sheet

         AS 2.1: Milling calculations and variables

      d. Answers to assignment sheet

      e. Job sheet

         JS 2.1: Calculate and set spindle speeds and feeds

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

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2. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Provide the students with the necessary tables of cutting speeds and feeds per tooth and formulas for the completion of assignment sheets and the unit test.

2. Encourage the use of pocket calculators.

B. Suggested student activity

1. Set up a table displaying a variety of milling cutter types. Permit the students to practice handling and identifying the tools and their applications.

C. Suggested supplemental materials (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

1. Vertical Milling Machine Cutters, Part I (MS-86-362) (video). Sedalia, MO: State Fair Community College, 1986.

2. Vertical Milling Machine Cutters, Part II (MS-86-363) (video). Sedalia, MO: State Fair Community College, 1986.

MODULE: MILLING

UNIT IV: CUTTING-TOOL VARIABLES

LESSON 1: CUTTING-TOOL TYPES

I. Terms and definitions

A. Ball end mill--special-purpose end mill used to machine concave grooves

B. End mill--mounted in the vertical position to cut on sides or ends (the most commonly used vertical milling cutter)

C. Left-hand end mill--cuts while turning in a clockwise direction (If viewed from the end, the cutting flutes twist to the left.)

D Plain milling cutter--typical arbor mount milling cutter which is cylindrical with teeth on the periphery only; has no side-cutting capability

E. Roughing end mill--heavy-duty end mill with multiple flutes for removing a large amount of material quickly (also known as a "hog mill")

F. Shell end mill--heavy duty end mill which features separate shank and cutting portions

G. T-slot cutter--special-purpose milling cutter for machining T-slots

H. Woodruff key seat cutter--special-purpose cutter for machining Woodruff key seats

II. Types of milling cutters

A. End mills are especially suited for vertical milling machines.

1. Purpose

a. Can cut on the side and end simultaneously

b. Versatility--can cut slots, pockets and slab, etc.

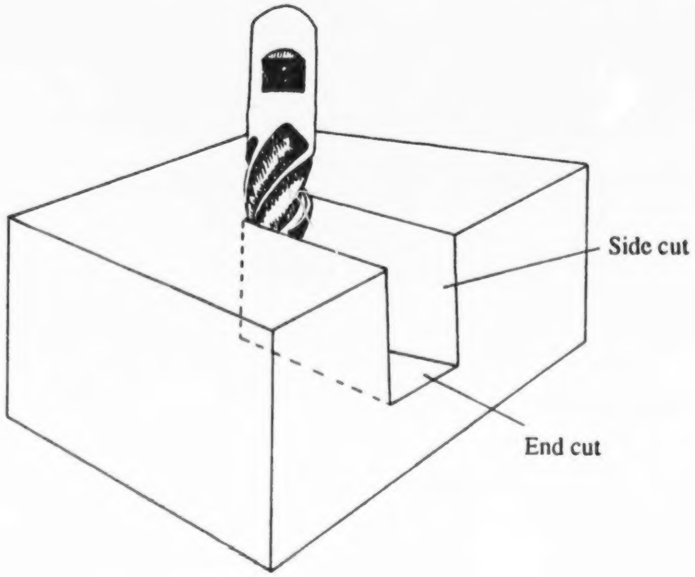
2. Classifications

a. Straight or tapered shank

b. Two or more flutes

c. Solid, cemented carbide or replaceable insert teeth

d. Inch or metric diameter

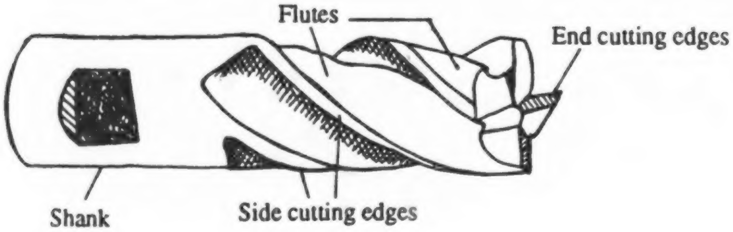

Side cut
End cut

3. Parts of the end mill

   a. Shank (with tang if tapered)

   b. Flutes

   c. End


Flutes
End cutting edges
Shank
Side cutting edges

4. Special types of end mills **(HO 1.1)**

   a. Ball end mill

   b. Roughing end mill

   c. Left hand end mill

   d. Shell end mill

B. Form-type cutters **(HO 1.2)**

   1. Radius

    2. T-slot
    3. Chamfer
    4. Dovetail
    5. Woodruff key seat

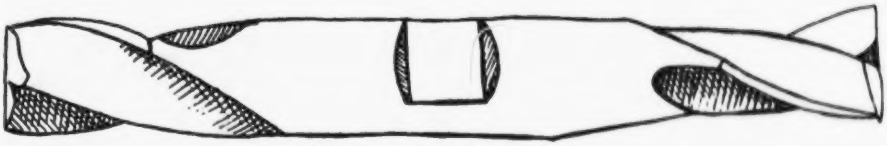
C. The arbor-mount milling cutter is especially suited for horizontal milling.

    1. Plain milling cutter
    2. Heavy-duty milling cutter
    3. Side milling cutter
    4. Carbide-tipped milling cutter
    5. Slitting saw
    6. Angle cutter
    7. Gear milling cutter

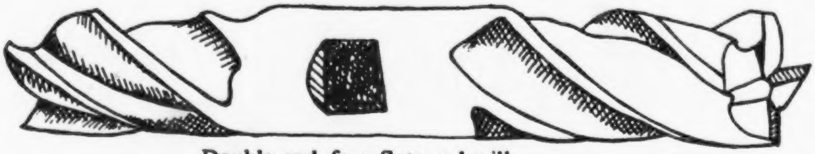
D. Other cutters used on milling machines

    1. Boring tools
    2. Fly cutters
    3. Any cutting or drilling tools which can be held in a drill chuck
        a. Twist drills
        b. Counterbores
        c. Countersinks
        d. Taps
        e. Center drills

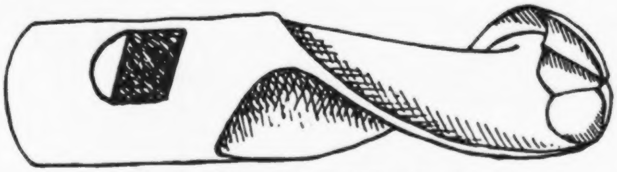
TYPES OF END MILLS



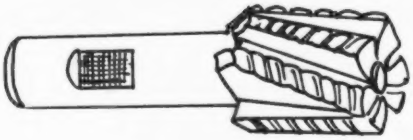
Double-end, two-flute end mill



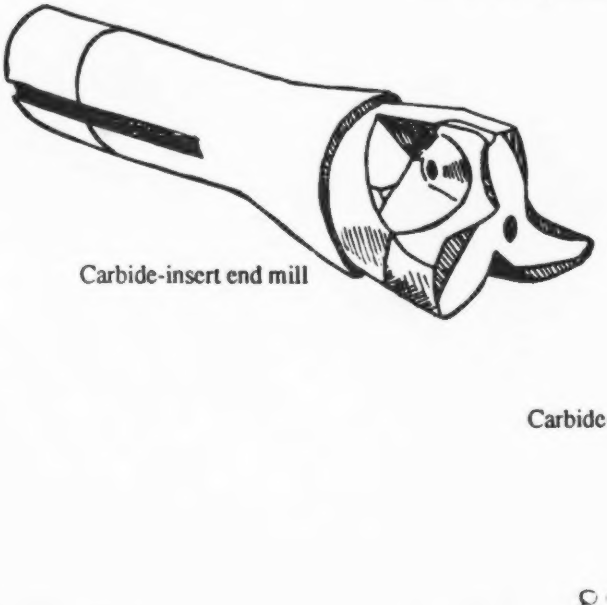
Double-end, four-flute end mill



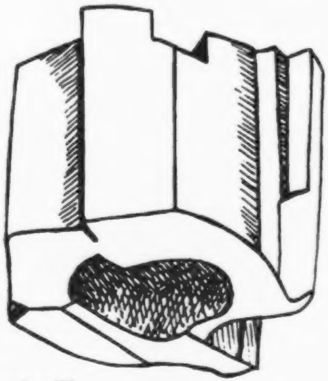
Single-end, two flute, ball end mill



Roughing-type end mill

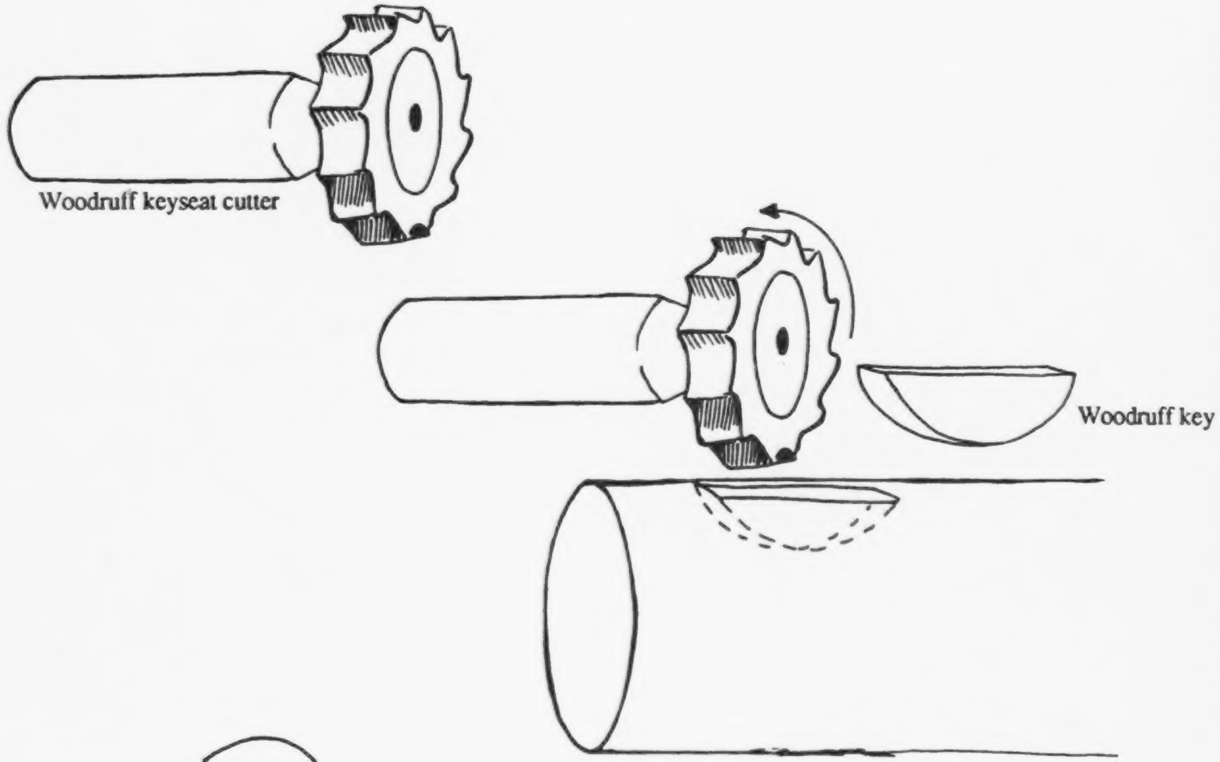


Carbide-insert end mill

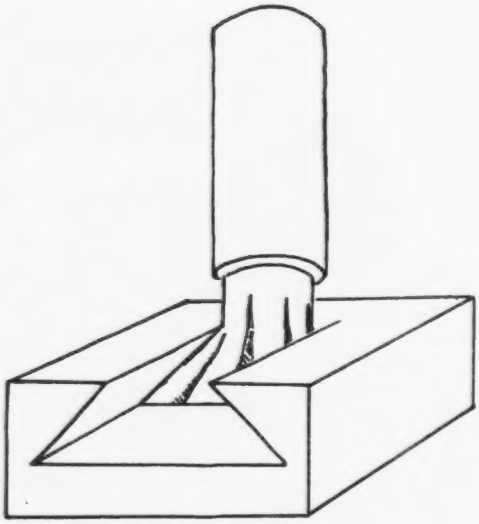


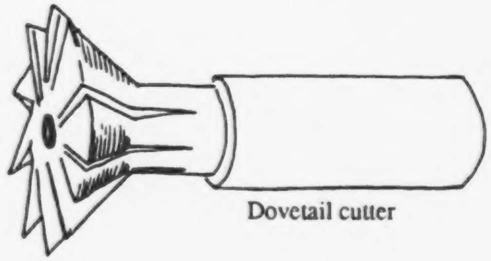
Carbide-tipped shell end mill

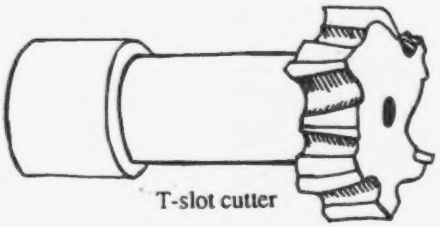
SPECIAL FORM AND PURPOSE END MILLS

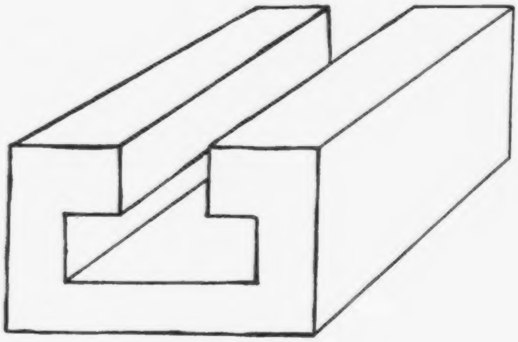

Woodruff keyseat cutter

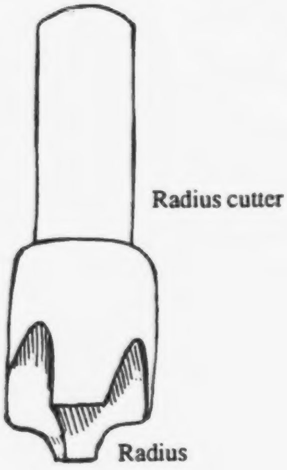
Woodruff key

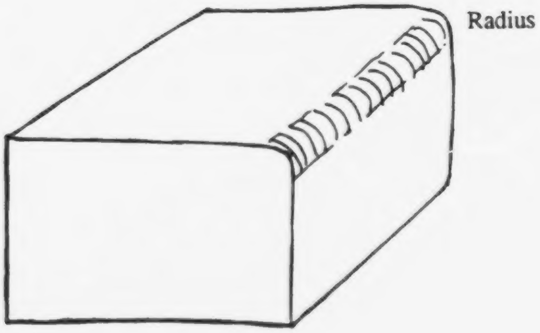



Dovetail cutter


T-slot cutter

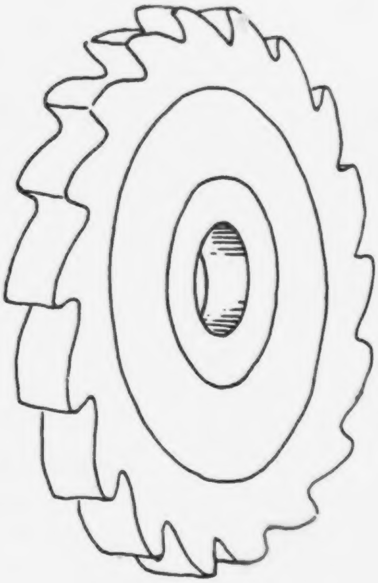



Radius cutter
Radius

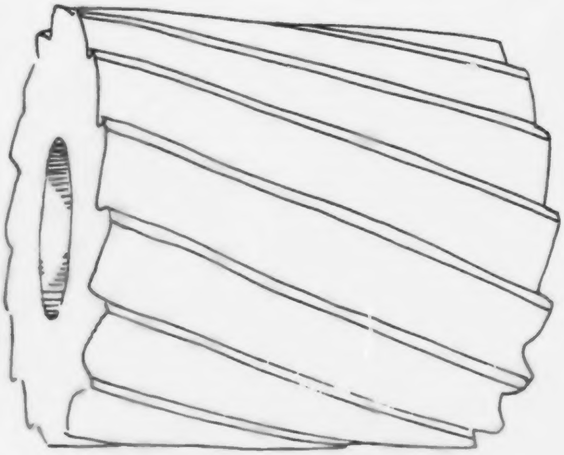

Radius

HO 1.3

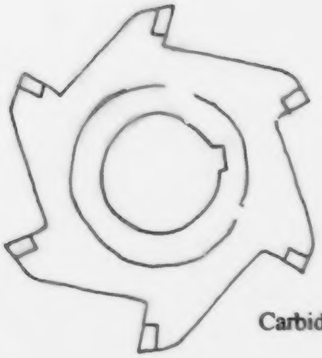
ARBOR-MOUNT MILLING CUTTERS



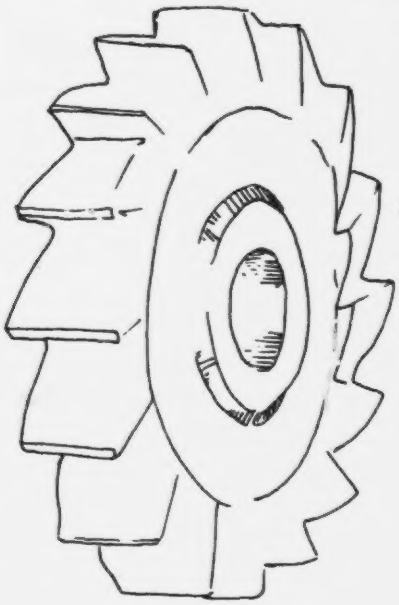
Plain milling cutter



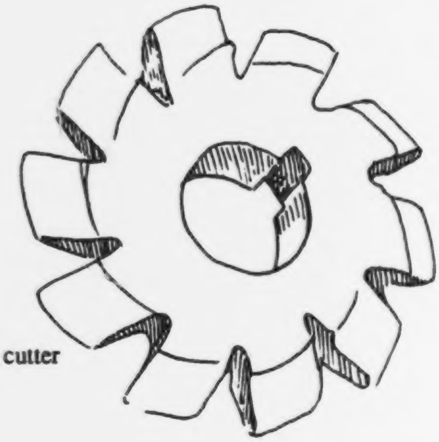
Heavy-duty plain milling cutter



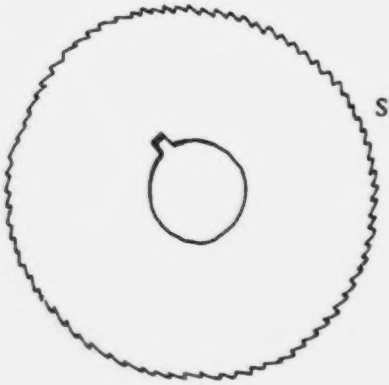
Carbide-tipped milling cutter



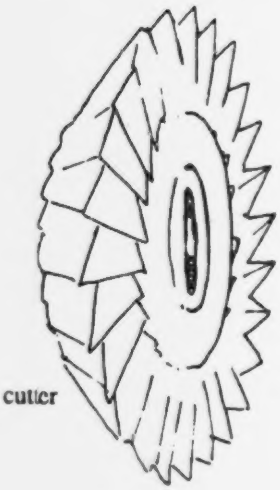
Side milling cutter



Gear milling cutter



Slotting jaw



Angle cutter

CUTTING-TOOL TYPES

Define the terms below.

1. Ball end mill:

2. End mill:

3. Left-hand end mill:

4. Plain milling cutter:

5. Roughing end mill:

6. Shell end mill:

7. T-slot cutter:

8. Woodruff key seat cutter:

Identify the following illustrated tools. NOTE: Some blanks will not have a corresponding illustration.

____ 9. Angle cutter

____ 10. Ball end mill

____ 11. Carbide insert cutter

____ 12. Carbide-tipped shell end mill

____ 13. Dovetail cutter

____ 14. End mill

____ 15. Gear milling cutter

____ 16. Heavy-duty plain milling cutter

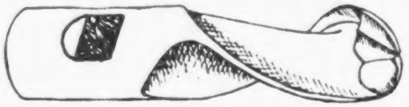
____ 17. Radius cutter

____ 18. Roughing-type end mill

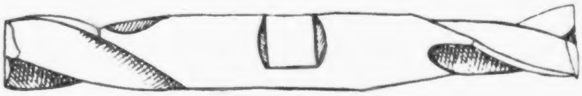
____ 19. Side milling cutter

____ 20. Woodruff key seat cutter

a.



b.



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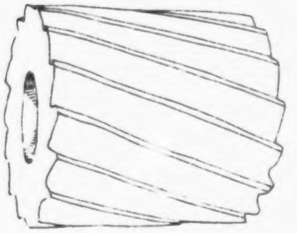
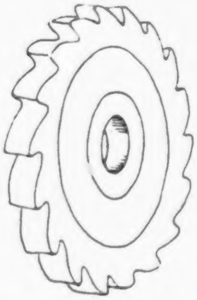
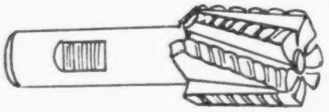


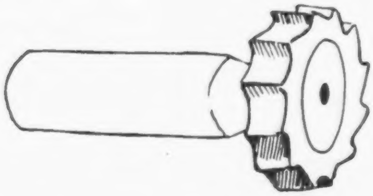
d.



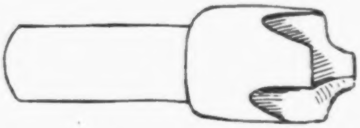
e.



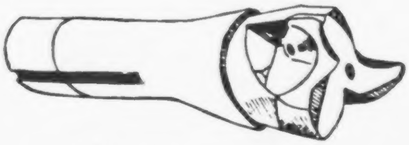
ab.



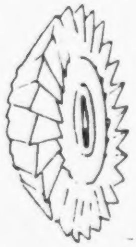
ac.



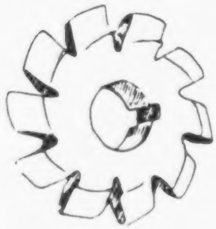
ad.



ae.



bc.



ANSWERS TO AS 1.1

1. Special-purpose end mill for machining concave grooves
2. Vertical milling cutter which is mounted in a vertical position. It can cut on sides or ends.
3. Milling cutter which is designed to cut while turning in a clockwise direction (If viewed from the end, the cutting flutes twist to the left.)
4. Typical arbor mount milling cutter which is cylindrical with teeth on the periphery only (It has no side-cutting capability.)
5. Heavy-duty end mill with multiple flutes for removing large amounts of material quickly
6. Heavy-duty end mill which features separate shank and cutting portions
7. Special-purpose milling cutter for machining T-slots
8. Special-purpose cutter for machining Woodruff key seats
9. ae
10. a
11. ad
12. (no answer)
13. (no answer)
14. b
15. bc
16. c
17. ac
18. e
19. d
20. ab

MODULE: MILLING

UNIT IV: CUTTING-TOOL VARIABLES

LESSON 2: MILLING CALCULATIONS AND VARIABLES

I. Terms and definitions

   A. Cutting speed--speed of the circumference of the milling cutter; expressed in meters per minute (mpm), feet per minute (fpm) or surface feet per minute (sfpm); linear distance the cutting edge travels in one minute. (Cutting speed varies according to materials and set-up factors.)

   B. Feed rate--rate at which the workpiece is moved across the cutter; expressed in millimeters/inches per cutter revolution or millimeters/inches per minute

   C. Machinability index--a relative indication of the ease with which a material can be machined. It is based on AISI 1112 as 100%. It is an important factor in determining cutting speed.

   D. rpm--revolutions per minute; the number of times the cutter turns in a minute (also the spindle speed)

   E. Spindle speed--rpm setting of the spindle

II. Cutting speed and spindle rpm variables

   A. There is no one best cutting speed for milling.

      1. The average speed is determined and then varied according to results obtained.

      2. The cutting speed depends on the material; suggested values are listed in tables.

         a. The table assumes use of a high-speed steel cutting tool.

         b. Reduce the speed for carbon steel.

         c. Increase the speed for cast alloys and carbide.

   B. Cutting speed is determined by rpm.

      1. Spindle rpm is set by using a variable speed drive or by changing belts.

      2. Factors needed to calculate the rpm setting

         a. Cutting speed (from table)

         b. Diameter of the cutter

      3. Formulas

         a. Metric

$$\text{rpm} = \frac{\text{c.s. (mpm)} \times 1000}{\text{D (mm)} \times \pi}$$

         b. Inch

$$\text{rpm} = \frac{\text{c.s (fpm)} \times 12}{\text{D (in.)} \times \pi}$$

c. Simplified

$$\text{rpm} = \frac{4 \times \text{c.s. (fpm)}}{D''}$$

III. Feed rate calculations

A. Importance of the feed rate setting

1. It determines the overall efficiency of the machining process.

2. Too high a feed will result in broken cutting tools.

3. Too slow a feed with high cutting speed will cause burning of the cutter.

B. Manual feed

1. The operator turns the table ball cranks manually.

2. Manual feeding requires good judgment.

a. Start with a slow feed and increase as possible.

b. Feed quickly with light cuts and slowly with heavy cuts.

c. Small cutters require slow feed rates to prevent fracture.

C. Calculating feed per minute

1. Factors to calculate feed (F)

a. Cutter rpm (as determined by cutting speed)

b. Number of teeth (T)

c. Feed per tooth per revolution (R) obtained from a table. It indicates the recommended chip load which a tooth can withstand. If R is exceeded, the tooth will break.

2. Formula: $F = R \times T \times \text{rpm}$

3. Factors affecting the actual feed rate setting
    a. Depth of cut
    b. Width of cut
    c. Cutter diameter
    d. Cutting toolholder
    e. Machine power
    f. Machine rigidity
    g. Accuracy desired
4. Milling feed tips
    a. Make heavy cuts for roughing and lighter cuts for finishing.
    b. Do not stop feeding in the middle of a cut. This will create an undercut area.

IV. Cutting fluids for milling

A. Types
1. Mineral
2. Sulphur-based
3. Soluble oils
4. Water-based synthetics
5. Compressed air

B. Application
1. Cutting fluids cool the tool and clear large volumes of chips.
2. Delivery
    a. Mist
    b. Flood
    c. Pressurized
3. Delivery must be constant to prevent cutter damage.

CAUTION: Safety guards must be in place to prevent chips and fluid from flying.

FEEDS AND SPEEDS FOR MILLING

Feeds per Tooth for Milling with High-Speed Steel Cutters

Material	End Mills[1]	Shell end and Face Mills	Plain Mills		Slitting Saws	Form-Relieved Mills
			Heavy-Duty	Light-Duty		
Low-carbon steel, free-machining	0.08 (0.003)*	0.20 (0.008)	0.25 (0.010)	0.13 (0.005)	0.08 (0.003)	0.10 (0.004)
Low-carbon steel	0.08 (0.003)	0.15 (0.006)	0.20 (0.008)	0.13 (0.005)	0.08 (0.003)	0.08 (0.003)
Medium-carbon steel	0.08 (0.003)	0.15 (0.006)	0.20 (0.008)	0.13 (0.005)	0.05 (0.002)	0.08 (0.003)
High-carbon steel	0.05 (0.002)	0.10 (0.004)	0.10 (0.004)	0.05 (0.002)	0.05 (0.002)	0.05 (0.002)
Stainless steel, free-machining	0.08 (0.003)	0.20 (0.008)	0.20 (0.008)	0.15 (0.006)	0.05 (0.002)	0.05 (0.002)
Stainless steel	0.05 (0.002)	0.10 (0.004)	0.15 (0.006)	0.10 (0.004)	0.05 (0.002)	0.05 (0.002)
Cast iron, soft	0.10 (0.004)	0.20 (0.008)	0.31 (0.012)	0.20 (0.008)	0.10 (0.004)	0.10 (0.004)
Cast iron, medium	0.08 (0.003)	0.15 (0.006)	0.25 (0.010)	0.15 (0.006)	0.08 (0.003)	0.08 (0.003)
Malleable iron	0.10 (0.004)	0.20 (0.008)	0.25 (0.010)	0.15 (0.006)	0.08 (0.003)	0.08 (0.003)
Brass and bronze, medium	0.08 (0.003)	0.20 (0.008)	0.25 (0.010)	0.15 (0.006)	0.08 (0.003)	0.08 (0.003)
Aluminum, wrought, cold-drawn	0.10 (0.004)	0.25 (0.010)	0.36 (0.014)	0.20 (0.008)	0.10 (0.004)	0.13 (0.005)

[1] Feeds cited are for 12.7 mm (1/2") diameter end mills taking a 6.35 mm (1/4") depth of cut. For finishing cuts, reduce the above feed rates by about 50%.

*millimeters (inches)

Cutting Speeds for Milling Roughing Cuts with High-Speed Steel Cutters

Material	Cutting Speed Range	
	mpm*	fpm**
Low-carbon steel	18.3-24.4	60-80
Medium-carbon steel	18.3-24.4	60-80
High-carbon steel	15.2-21.4	50-70
Tool steel	15.2-21.4	50-70
Stainless steel	15.2-24.4	50-80
Gray cast iron	15.2-24.4	50-80
Malleable iron	24.4-30.5	80-100
Aluminum and its alloys	121.9-304.8	400-1000
Brass	61.0-91.4	200-300
Bronze	30.5-61.0	100-200

*meters per minute

**feet per minute

Suggested speeds may be varied as follows

Finishing cuts — increase 25-50%

Carbon-steel cutters — decrease about 50%

Cast-alloy tipped cutters — increase 50-75%

Carbide tipped cutters — increase 200-400%

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MILLING CALCULATIONS AND VARIABLES

Define the following terms.

1. Cutting speed:

2. Feed rate:

3. Machinability index:

4. rpm:

5. Spindle speed:

Use the cutting speed table to find the cutting speed (when using a high-speed steel cutting tool) for each of the materials listed. Answer in both metric and inch units.

6. Free-machining steel 1111

Metric: _________ , inches: _________

7. Tool steels D1-D7

Metric: _________ , inches: _________

8. Aluminum casting alloys

Metric: _________ , inches: _________

9. Calculate the spindle rpm setting for machining cold-drawn wrought aluminum with a 0.500" high-speed steel cutter. Use the simplified formula.

Metric: _________ , inches: _________

10. Recalculate #9 assuming a carbide cutting tool. Use the simplified formula.

Metric: _________ , inches: _________

Find the feed per tooth for the materials listed assuming a high-speed steel end mill. Answer in both metric and inch units.

11. Low carbon steel, free machining

Metric: _________ , inches: _________

12. Stainless steel, free machining

Metric: _________ , inches: _________

13. Cast iron, medium

Metric: _________ , inches: _________

14. Calculate the feed rate (ipm, mpm) for machining soft cast iron with a 0.250" diameter two-flute end mill made of high-speed steel. Assume a cutting speed of 80 fpm.

NOTE: To solve this problem, first calculate spindle rpm. Answer in both metric and inch units.

Metric: _________ , inches: _________

List seven factors which can affect the actual feed rate setting.

15.

16.

17.

18.

19.

20.

21.

ANSWERS TO AS 2.1

1. Speed of the circumference of the milling cutter expressed in meters per minute (mpm), feet per minute (fpm) or surface feet per minute (sfpm); linear distance the cutting edge travels in one minute

2. Rate at which the workpiece is moved across the cutter; expressed as millimeters/inches per cutter revolution or millimeters/inches per minute

3. A relative indication of the ease with which a material can be machined; based on AISI 1112 as 100%

4. Revolutions per minute; the number of times the cutter turns in a minute; also, spindle speed

5. The rpm setting of the spindle

6. 36.6-48.8 mpm, 120-160 fpm

7. 9.1-18.3 mpm, 30-60 fpm

8. 182.9-304.8 mpm, 600-1000 fpm

9. 4000-6400 rpm

10. 8000-14400 rpm

11. 0.08 mm, 0.003"

12. 0.08 mm, 0.003"

13. 0.08 mm, 0.003"

14. 9.6 ipm

15-21. Depth of cut
Width of cut
Cutting diameter
Cutting toolholder
Machine power
Machine rigidity
Accuracy desired

JS 2.1

CALCULATE AND SET SPINDLE SPEEDS AND FEEDS

Equipment:

Cutting speed and feed rate tables
Wrench (if belt drive is used)
Pocket calculator
Vertical milling machine (Series I type)
Operator's manual for the machine

NOTE: Always review the contents of the operator's manual before attempting to install, operate or adjust any equipment.

Procedure:	Evaluation 3	 2	 1	 N
1. Assuming that the workpiece material is wrought aluminum and the cutter is a 0.375" diameter two-flute end mill made of high-speed steel, calculate the spindle rpm.	___	___	___	___
2. Set the spindle rpm. Adjust the back gear in or out as needed. Move belts to achieve the closest possible value or adjust the variable speed drive.	___	___	___	___

CAUTION: Do not move the variable speed drive unless the spindle is turning. The drive could be damaged.

CAUTION: V-belts and sheaves (pulleys) present a significant hazard to limbs if handled improperly. Before adjusting the belts, make sure that the power to the machine is off and that no one can accidentally turn on the machine.

3. Calculate the feed rate in both inch and metric units.	___	___	___	___
4. Adjust the power feed device to provide the desired feed rate.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is the student's final evaluation for competencies J6 and J8.

MODULE: MILLING

UNIT IV: CUTTING-TOOL VARIABLES

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which is a special-purpose end-mill for machining concave grooves?

a. Ball end mill
b. T-slot cutter
c. Shell end mill
d. Angle cutter
e. Gear cutter

____ 2. Which is a commonly used vertical milling cutter which can cut on its sides or end?

a. Ball end mill
b. Shell end mill
c. Roughing end mill
d. Carbide insert end mill
e. All of the above

____ 3. Which is a heavy-duty end-mill with multiple flutes for removing large amounts of material quickly (also called a "hog mill")?

a. Ball end mill
b. Plain milling cutter
c. Gear cutter
d. Slitting saw
e. Roughing end mill

____ 4. Which describes the linear speed of a milling cutter's circumference?

a. Feed rate
b. Cutting speed
c. rpm
d. Feed per tooth
e. None of the above

____ 5. Identify the term used to describe the movement of the cutter across the workpiece.

a. Feed
b. Speed
c. rpm
d. Spindle speed
e. Flutes

____ 6. Identify the term describing the relative ease with which a material can be machined.

a. Machinability index
b. Feed rating
c. Cutting speed
d. rpm setting
e. None of the above

____ 7. Which of the following is not a consideration when setting the spindle rpm?

a. Workpiece material
b. Cutting tool material
c. Desired feed rate
d. Cutter diameter
e. Units desired (metric or inch)

____ 8. Which of the following would not be a result of a feed rate that is too low?

a. Burned tool
b. Broken tool
c. Improved surface finish
d. Lost productivity and efficiency
e. All of the above

____ 9. Which statements regarding manual machine feeding is false?

a. The operator must turn the handwheel constantly to cut the material.
b. The machinist must utilize judgment and experience.
c. Small cutters require higher feed rates to prevent breakage.
d. The number of teeth on the cutter can influence the feed rate.
e. Lighter cuts should be taken on finishing passes.

____ 10. Which statement regarding cutting fluids is true?

a. Clears chips
b. Extends tool life
c. Cools tool during cutting
d. Have various delivery methods
e. All of the above

____ 11. Which of the following is not a good cutting fluid for milling?

a. Air
b. Water
c. Soluble oil
d. Mineral oil
e. Water-based synthetics

Use HO 2.1 to answer the following questions.

____ 12. Which is the proper cutting speed for milling wrought aluminum alloys?

a. 120-160 fpm
b. 24.4-36.6 mpm
c. 182.9-304.8 mpm
d. 500-800 fpm
e. 800-1000 fpm

____ 13. Calculate the spindle rpm setting for machining 220 commercial annealed brass (cutting speed 140 fpm) with a 1/2" diameter end mill.

a. 800 rpm
b. 1000 rpm
c. 15000 rpm
d. 200 rpm
e. None of the above

____ 14. What is the recommended feed per tooth for carbide end mills when machining wrought aluminum?

a. 0.10 mm
b. 0.08 mm
c. 0.05 mm
d. 0.02 mm
e. None of the above

____ 15. Calculate the feed rate in inches per minute for machining stainless steel (free machining, cutting speed = 80 fpm) using a one-inch diameter, four-flute, carbide-insert end mill. Use the simplified formula for the rpm calculation.

a. 3.84 ipm
b. 38.4 ipm
c. 83.4 ipm
d. 8.34 ipm
e. None of the above

ANSWERS TO UNIT TEST

1. a
2. e
3. e
4. b
5. a
6. a (J8)
7. c (J8)
8. c
9. c (J8)
10. e (J7)
11. b (J7)
12. d (J6)
13. e (J6)
14. a (J6)
15. a (J6)

MODULE: MILLING

UNIT V: BASIC SET-UP ACTIVITIES

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to set up a milling machine so that operations can be performed accurately. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Match terms and definitions concerning milling head alignment.

1.2 Align mill head to table. (competency J3, JS 1.1)

2.1 Match terms and definitions concerning mounting attachments and work to the milling table.

2.2 Align vise and angle block to table. (competency J4, JS 2.1 and 2.2)

2.3 Identify the parts of a swivel-base milling vise and clamping kit.

2.4 Align workpiece mounted on machine table. (competency J5, JS 2.3)

MODULE: MILLING

UNIT V: BASIC SET-UP ACTIVITIES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

   1. Lesson 1: MILLING HEAD ALIGNMENT

      a. Information outline

      b. Transparency masters

         TM 1.1: Back gear lever
         TM 1.2: Milling head pitch
         TM 1.3: Milling head yaw

      c. Job sheet

         JS 1.1: Align mill head to table

   2. Lesson 2: MOUNTING ATTACHMENTS AND WORK TO THE MILLING TABLE

      a. Information outline

      b. Transparency master

         TM 2.1: Indicating surfaces

      c. Job sheets

         JS 2.1: Align vise with milling table
         JS 2.2: Align angle plate with milling table
         JS 2.3: Align workpiece mounted on machine table

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

4. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

B. Curriculum guide

1. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

2. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. The head alignment in JS 1.1 must be performed to a tolerance of ± 0.0005". All other job sheets in this unit require a tolerance of ± 0.001".

2. Completion of this unit requires that the student handle heavy milling machine accessories (vises, angle plates, etc.). The student should review proper procedures for lifting in the safety module.

B. Suggested supplemental material

1. Tramming the Head and Indicating the Vise on the Vertical Mill (MS-86-361) (video). Sedalia, MO: State Fair Community College, 1986. (Available for purchase from SFCC; available for loan from Missouri Vocational Resource Center, phone 800/392-7217 or 314/882-9610)

MODULE: MILLING

UNIT V: BASIC SET-UP ACTIVITIES

LESSON 1: MILLING HEAD ALIGNMENT

I. Terms and definitions **(TM 1.1-1.3)**

  A. Back gear lever--milling head lever which controls the engagement of the back gear to achieve a low speed range. When it is engaged and the mill is off, the back gear can be used to hold the milling spindle stationary while the drawbar is turned.

  B. Pitch--the front-to-back tilting of the milling head of a vertical milling machine

  C. Tram--procedure for squaring the milling head to the table so that the angles of the pitch and yaw are both 90° (also alignment)

  D. Yaw--the side-to-side tilting of a vertical milling machine's head

II. Milling head alignment

  A. Correct alignment is important since it affects the accuracy of all machining operations performed on a vertical milling machine, especially precision boring.

  B. The head may need realignment after it has been moved to perform a special operation or following heavy cutting.

  C. Bolts restrain the head movement.

    1. Location

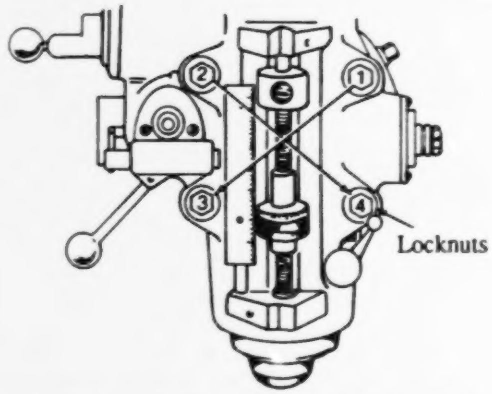
      a. Face of milling head for yaw

      b. Side of ram for pitch

    2. The correct tightening of bolts is important.

      a. Use a 1-3-2-4 pattern.

      b. Tighten gradually and alternately to ensure even tightening.



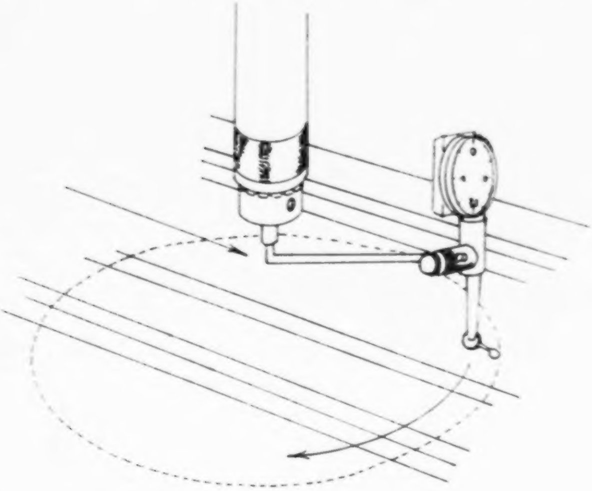
Credit: Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983, pg. 259. Used by permission.

  D. Procedure notes

    1. Degree markings provide rough settings.

    2. The indicator sweep is preferred for high accuracy, especially for boring. The adjustment should be to within ± 0.0005".

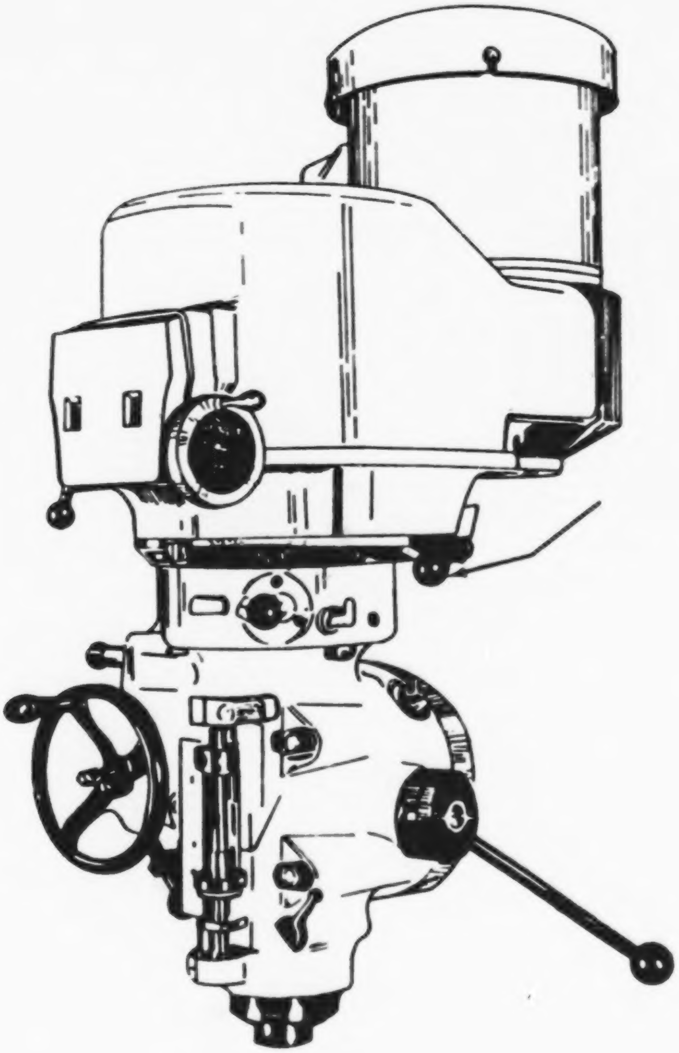
3. The dial test indicator is used to sweep the milling table and read the condition of the head alignment.



E. Procedure guidelines

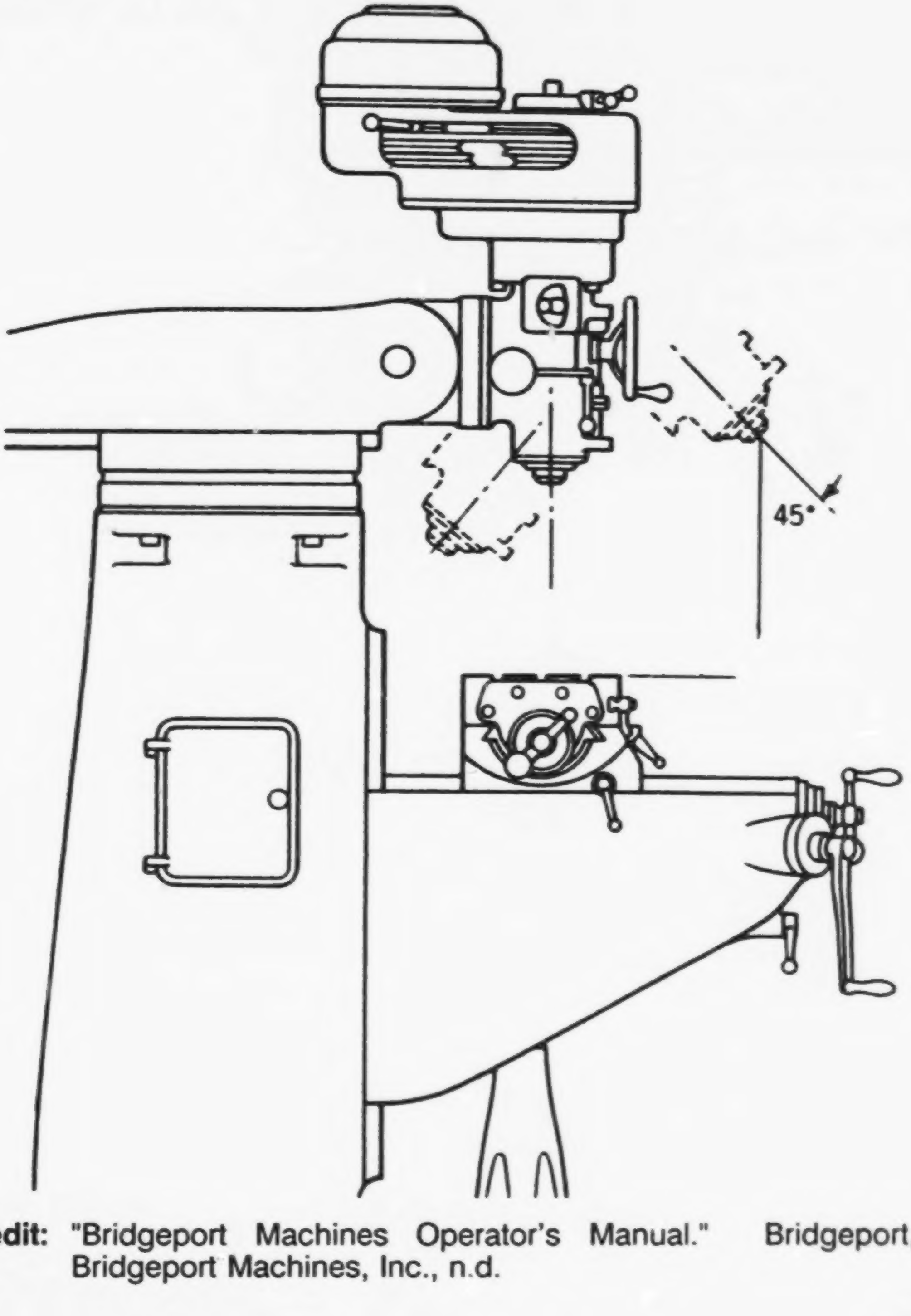
1. Disconnect the power to the milling machine. The indicator will be mounted in the milling spindle. If the spindle is turned on while the indicator is in place, the indicator could be damaged.
2. Remove any vises or other attachments from the milling table. Remove any chips or other debris and wipe the table clean.
3. Mount the indicator on the extension attachment. Mount in the spindle. Disengage the back gear.
4. Set the indicator dial at zero with no contact. Raise the knee until the indicator contacts and reads one-half of the available scale.
5. Turn the drawbar to "sweep" the indicator in a complete circle. Be careful when crossing T-slots to avoid knocking the indicator out of adjustment. The indicator will read the same all around if the head is aligned.
6. Adjust the pitch and then the yaw. Repeat as necessary. Tighten bolts gradually and alternately in a 1-3-2-4 pattern. Check the indicator reading again. Over-tightening can adversely affect the adjustment of the machine.
7. Check the reading. The indicator reading should be the same all around. Repeat above steps as required.
8. Remove the indicator from the spindle. Put tools away.

BACK GEAR LEVER



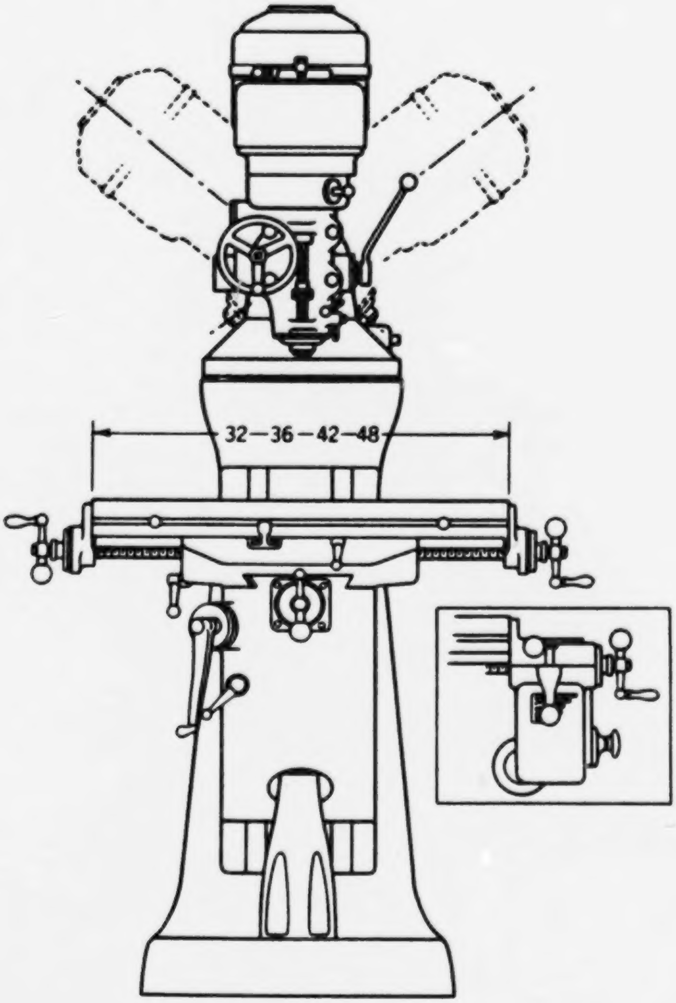
Credit: Bridgeport Machines, Inc.

MILLING HEAD PITCH



Credit: "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

MILLING HEAD YAW



Credit: "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

JS 1.1

ALIGN MILL HEAD TO TABLE

Equipment:

Dial test indicator and attachments
Wrench for the drawbar
Wrench for the head bolts
Soft mallet

	Procedure	Evaluation			
		3	2	1	N
1.	Disconnect power to the milling machine. Engage the back gear. Lower the knee to allow working space, as necessary. Remove any vises or other attachments from the milling table. Remove any chips or other debris and wipe the table clean.	—	—	—	—
2.	Mount the indicator on the extension attachment.	—	—	—	—
3.	Obtain an R-8 collet that fits the extension. Mount the collet loosely on the milling-machine spindle (3-4 turns of the drawbar). Insert the indicator extension into the collet and tighten the drawbar snugly. Be careful not to damage the indicator.	—	—	—	—
4.	Disengage the back gear.	—	—	—	—
5.	Set the indicator dial at zero with no contact. Raise the knee until the indicator makes contact and reads one-half of the available scale.	—	—	—	—
6.	Grasp the drawbar at the top of the machine and turn the spindle to "sweep" the indicator in a complete circle. Be careful when crossing the T-slots to avoid knocking the indicator out of adjustment. If the head is aligned, the indicator will read the same all around.	—	—	—	—
	CAUTION: Never turn on the power with an indicator on the spindle. Serious damage to the indicator could result.				
7.	Loosen the four bolts on the side of the ram which restrain the forward and backward pitch of the head. Sweep the indicator around, noting the difference in readings from front to back. While watching the indicator dial, turn the adjustment screw behind the ram until one-half of the difference of the two original readings has been removed.	—	—	—	—
8.	Sweep the indicator again and note the difference in readings at the front and back as before. Continue sweeping and adjusting until there is no difference in the two readings. The pitch of the head is now in adjustment.	—	—	—	—
9.	Tighten bolts gradually and alternately in a 1-3-2-4 pattern. Check the indicator reading again. Over-tightening can adversely affect the adjustment of the machine.	—	—	—	—
10.	Loosen the four bolts on the front which restrain side-to-side yaw of the milling head. Sweep the indicator around; note the difference in the readings from side to side. While watching the indicator dial, turn the adjustment screw on the side of the head until the indicator has been moved one-half of the difference of the two original readings.	—	—	—	—

11. Sweep the indicator again and note the difference in readings at each side as before. Continue sweeping and adjusting until there is no difference in the two readings. The yaw of the head is now in adjustment. ____ ____ ____ ____

12. Tighten bolts gradually and alternately in a 1-3-2-4 pattern. Check the indicator reading again. Over-tightening can adversely affect machine adjustment. ____ ____ ____ ____

13. Check the reading. The indicator reading should be the same all around. Repeat the steps above as required. ____ ____ ____ ____

14. Remove indicator from spindle. Put tools away. ____ ____ ____ ____

    NOTE: The maximum permissible variation in front-to-back and from side-to-side readings is ± 0.0005".

Average of above evaluations* ____ ____ ____ ____

*This average is the student's final evaluation for competency J3: Align mill head to table.

MODULE: MILLING

UNIT V: BASIC SET-UP ACTIVITIES

LESSON 2: MOUNTING ATTACHMENTS AND WORK TO THE MILLING TABLE

I. Terms and definitions

A. Angle plate--machining accessory which consists of two surfaces machined precisely at 90° to one another; used for set-up or for holding work for machining

B. Clamping kit--machining accessory used to fix workpieces or fixtures to the milling table; includes T-bolts, strap clamps, step blocks and studs

C. Datum (reference) surface--face of the workpiece from which other part features can be located for measurement or machining

D. Die truck--hydraulically or mechanically actuated cart for handling dies, vises and other heavy objects in the machine shop

E. Fixed vise jaw--jaw which does not move; provides the most reliable reference surface on the milling machine vise

F. Movable vise jaw--vise jaw which is mounted on a screw and moves in and out from the fixed jaw

G. Swivel-base milling vise--precision milling vise which features a swivelling base upon which the vise itself can be turned and set at various angles according to graduations machined on the base

H. Vise alignment blocks--small bars mounted on the bottom of milling accessories which provide for repeatable placement of the device in the milling table's T-slots

II. Principles of aligning the workpiece **(TM 2.1)**

A. Squaring the workpiece to the movement of the milling table is the ultimate goal to ensure accurate work, whether aligning a vise, milling attachment or workpiece.

B. A dial test indicator is used to check the alignment of the milling accessory or workpiece.

C. Alignment objectives

1. A fixed vise jaw should align with table movement to within ± 0.001".

2. The vertical surface of an angle plate should align with the table travel to within ± 0.001".

3. When mounting a workpiece directly to the table, the selected datum (reference surface) should align with table movement to within ± 0.001".

4. Assuming that the surfaces to be indicated are flat, indicator readings on either end of the workpiece will be the same when alignment has been achieved.

D. Preparation

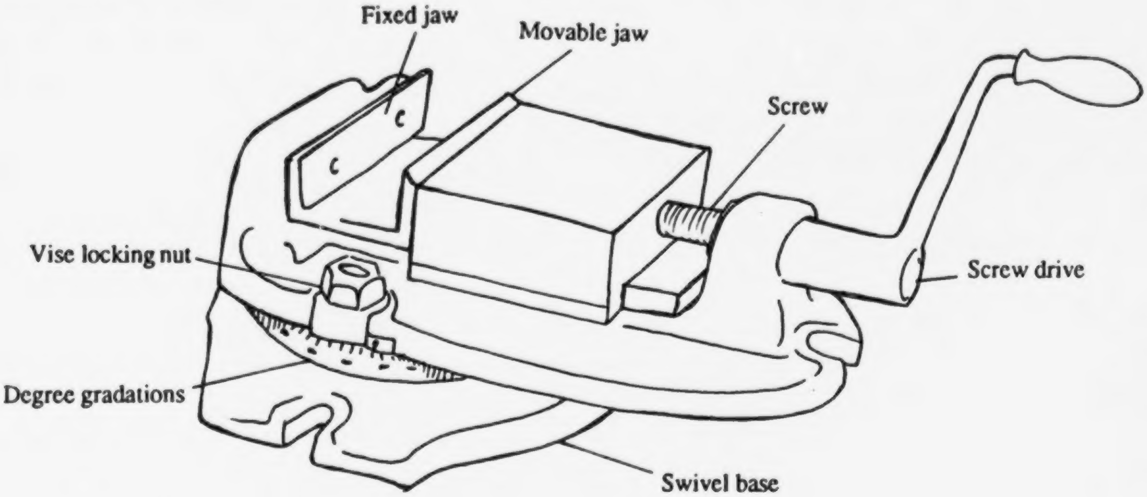
1. The milling table must be thoroughly clean and free from burrs and other undesirable surface features which may affect the mating of the milling table surface with the base of the vise or workpiece.

2. Also, the bottom of the vise must be clean and free from burrs.

III. Special equipment description, use and safety

A. Swivel-base milling vise

1. Parts


Fixed jaw
Movable jaw
Screw
Vise locking nut
Screw drive
Degree gradations
Swivel base

2. Handling milling vises

a. The vise is heavy and dangerous.

b. Obtain assistance when moving it.

c. Use a die truck to raise and lower it.

d. Position the milling table to minimize handling.

B. Clamping (hold-down) kit

1. Components

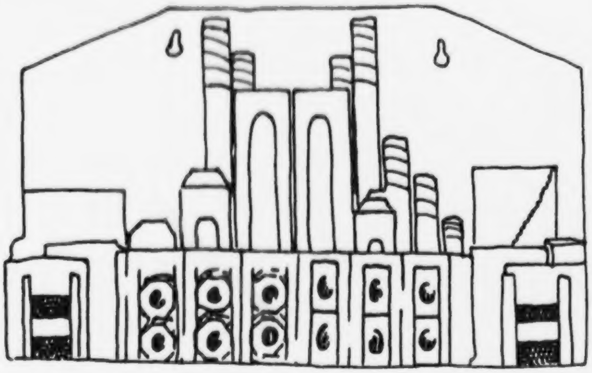
a. Studs

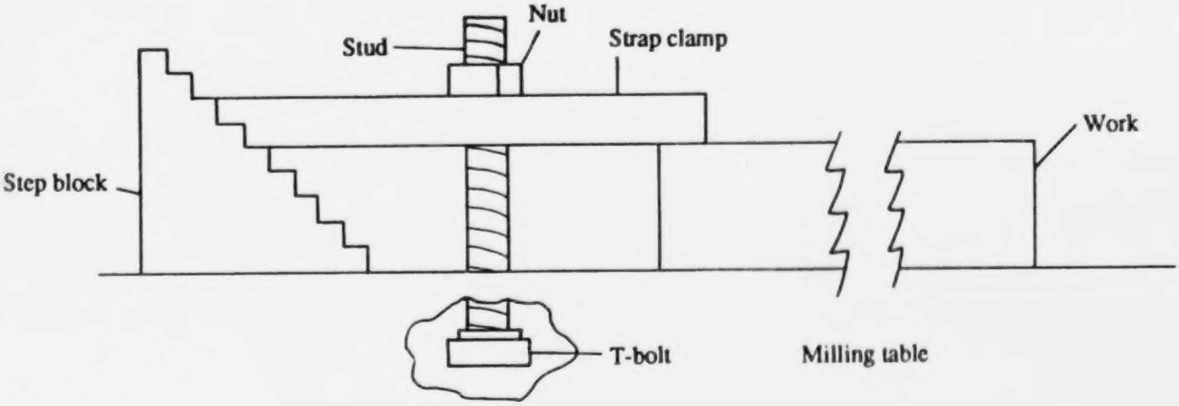
b. Bolts

c. T-bolts

d. Strap clamps

e. Step blocks



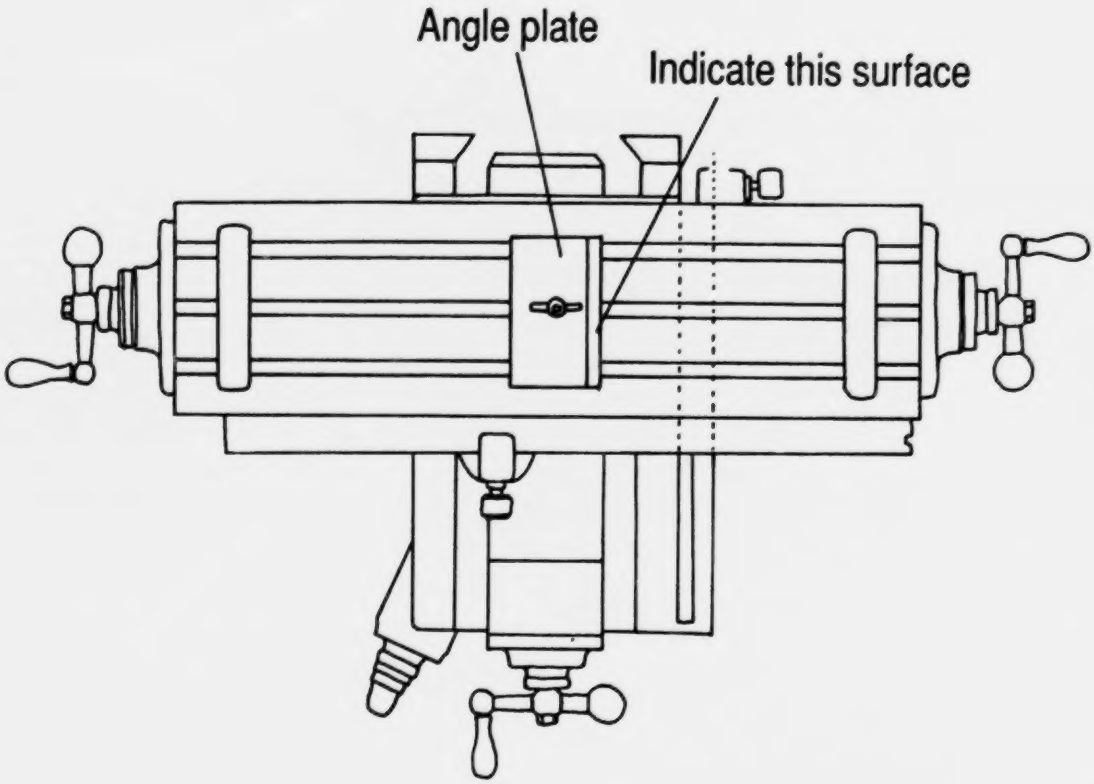

Nut
Stud
Strap clamp
Work
Step block
T-bolt
Milling table

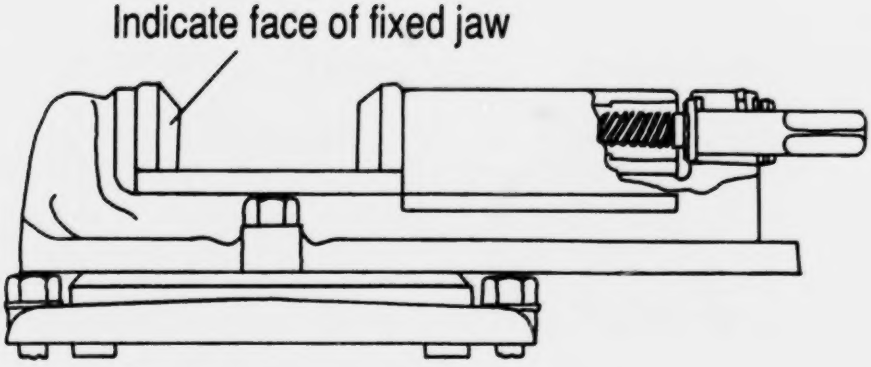
2. Principles of clamping

   a. Clamp the workpiece evenly to hold it flat and true.

   b. Strap clamps should be adjusted to be level with the table surface.

INDICATING SURFACES


Angle plate
Indicate this surface


Indicate face of fixed jaw

JS 2.1

ALIGN VISE WITH MILLING TABLE

Equipment:

Dial test indicator and attachments
Combination square
Clean rag or shop towel
Die truck, cart or hydraulic table
Wrench for drawbar
Wrench for vise swivel bolts
Wrench for T-bolts
Soft mallet

CAUTION: Always use proper procedures when handling milling machine work-holding accessories. Keep feet slightly spread apart and lift only with the legs. Also, take care to prevent injury to the hands when placing accessories on the milling table or bench. Watch for sharp chips. Ask for help when necessary.

		Evaluation			
Procedure:		3	2	1	N
1.	Obtain a swivel-base milling vise. Wipe the vise clean of all chips and debris. Turn the vise on its side on the workbench and wipe the bottom clean. Inspect for burrs and other damage. Remove any burrs with a small oilstone. Clean the bottom again to remove any abrasive material left by the oilstone.	___	___	___	___
2.	Take the vise to the milling machine with a die truck, cart or hydraulic table.	___	___	___	___
3.	Disconnect the power to the milling machine. Remove any cutting tools from the spindle. Lower the knee to permit working space, as necessary. Move the saddle out away from the column. Move the table over as far to the right as possible. Remove any chips or other debris and wipe the table clean.	___	___	___	___
4.	Estimate the longitudinal center of the milling table. Adjust the height of the die truck to that of the table. Pick up the vise and place it carefully on the table so that the alignment blocks (if any) on the bottom of the vise fit into the center T-slot. Slide the T-bolts into place and secure the swivel base to the table. Tighten the bolts gradually and alternately to be certain that the vise is level.	___	___	___	___
	NOTE: Place the vise on the table where it will be located. Do not slide the vise on the milling table surface because this can scratch both the milling table and the vise bottom.				
5.	Loosen bolts on the swivel and align the fixed vise jaw with the column using a combination square. Tighten bolts on the swivel slightly.	___	___	___	___
6.	Mount the indicator on the extension attachment. Mount the extension on the milling head. (Many Series I-type milling machines have a hole adjacent to the spindle to accommodate an indicator extension. If this feature is lacking, the indicator can be mounted in the spindle.)	___	___	___	___

7. Position the indicator so that it is in contact with the end of the fixed jaw's face for 1/4-1/2 of the available scale on the indicator. Zero the indicator dial. Move the saddle to permit the indicator to travel across the face of the jaw. Note the difference between the indicator reading at the opposite end of the jaw and the original reading. __ __ __ __

8. Lightly tap the corner of the vise diagonal to the indicator with a soft mallet until the indicator has moved equal to one-half the difference between the readings on the ends of the jaw. Sweep the face of the jaw as above and note any difference in the readings. __ __ __ __

9. Repeat step #8 until the reading on each end of the jaw is the same. __ __ __ __

10. Tighten swivel bolts snugly. Tighten bolts gradually and alternately to be certain that the vise is level. Check the alignment again to be certain that no movement occurred as the bolts were being tightened. __ __ __ __

    NOTE: Alignment of the vise must be performed to within ± 0.001".

Average of above evaluations* __ __ __ __

*This average is the student's partial evaluation for competency J4: Align milling machine attachments.

JS 2.2

ALIGN ANGLE PLATE WITH MILLING TABLE

Equipment:

Dial test indicator and attachments
Wrench for T-bolts
Combination square
Clamping kit
Angle plate
Soft mallet

	Procedure:	Evaluation 3	 2	 1	 N
1.	Disconnect the power to the milling machine. Engage the back gear. Lower the knee to permit working space, as necessary. Remove vises or other attachments from the table and cutting tools from the spindle. Remove any chips or other debris and wipe the table clean. Make certain that the table is free of burrs.	___	___	___	___
2.	Position the angle plate near the approximate center of the milling table with the appropriate clamping kit parts in place (see illustration). Square the angle plate with the edge of the milling table using a combination square. Lightly tighten the T-bolts.	___	___	___	___
3.	Mount the indicator on the extension attachment. Mount the extension to the milling head. (Many Series I-type milling machines have a hole adjacent to the spindle to accommodate an indicator extension. If this feature is lacking, the indicator can be mounted in the spindle in the appropriate collet.)	___	___	___	___
4.	Position the indicator so that it is in contact with one end of the vertical face of the angle plate for 1/4-1/2 of the available scale on the indicator. Zero the indicator dial. Move the saddle to permit the indicator to travel across the face of the plate. Note the difference between the original reading and the reading at the opposite end of the plate.	___	___	___	___
5.	Lightly tap the corner of the angle plate diagonal to the indicator with a soft mallet until the indicator has moved one-half the difference between the readings on the ends of the plate. Sweep the face as above and note any difference in the readings.	___	___	___	___
6.	Repeat step #5 until the reading on each end of the angle plate is the same.	___	___	___	___
7.	Carefully tighten T-bolts to secure the angle plate to the milling table. Recheck to be certain that the angle plate did not move while T-bolts were being tightened. NOTE: Alignment of the angle plate must be performed to within ± 0.001".	___	___	___	___
	Average of above evaluations*	___	___	___	___

*This average completes the student's evaluation for competency J4: Align milling machine attachments.

JS 2.3

ALIGN WORKPIECE MOUNTED ON MACHINE TABLE

Equipment:

Dial test indicator and attachments
Wrench for T-bolts
Clamping kit
Combination square
Soft mallet
Square workpiece

Procedure:	Evaluation 3	2	1	N
1. Disconnect power to the milling machine. Engage the back gear. Lower the knee to permit working space, as necessary. Remove any vises or other attachments from the table and cutting tools from the spindle. Remove any chips or other debris and wipe the table clean. Make certain that the table is free of burrs.	__	__	__	__
2. Position workpiece near the approximate center of the milling table with the appropriate clamping kit parts in place. Square workpiece with the edge of the table using a combination square. Lightly tighten T-bolts.	__	__	__	__
3. Mount the indicator on the extension attachment. Mount the extension to the milling head. (Many Series I-type milling machines have a hole adjacent to the spindle to accommodate an indicator extension. If this feature is lacking, the indicator can be mounted in the spindle in the appropriate collet.)	__	__	__	__
4. Position the indicator so that it is in contact with one end of a selected datum surface on the workpiece for 1/4-1/2 of the available scale on the indicator. Zero the indicator dial. Move the saddle to permit the indicator to travel across the face of the workpiece. Note the difference between the indicator reading at the opposite end of the workpiece and the original reading.	__	__	__	__
5. Lightly tap the corner of the workpiece diagonal to the indicator with a soft mallet until the indicator has moved one-half the difference between the readings on the ends of the workpiece. Sweep the face as above and note any difference in readings.	__	__	__	__
6. Repeat step #5 until the reading on each end of the workpiece is the same.	__	__	__	__
7. Carefully tighten T-bolts to secure the workpiece to the table. Recheck as above to be certain that the workpiece did not move while the T-bolts were being tightened.	__	__	__	__
NOTE: Workpiece alignment must be performed to within ± 0.001".				
Average of above evaluations*	__	__	__	__

*This average is the student's final evaluation for competency J5: Align workpiece mounted on machine table.

MODULE: MILLING

UNIT V: BASIC SET-UP ACTIVITIES

UNIT TEST

Match the part names with the letters on the illustration.

____ 1. Milling table

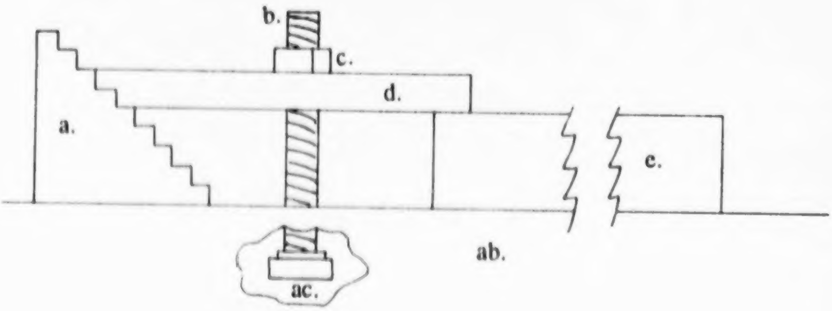
____ 2. Nut

____ 3. Step block

____ 4. Strap clamp

____ 5. Stud

____ 6. T-bolt



Select the option which answers the question or completes the statement.

____ 7. Identify the term indicating alignment of the milling machine head with the table.

a. Yaw
b. Pitch
c. Ram
d. Tram
e. None of the above

____ 8. Which term denotes the side-to-side movement of the milling head?

a. Tram
b. Align
c. Pitch
d. Yaw
e. None of the above

____ 9. Which term denotes the front-to-back movement of the milling head?

a. Pitch
b. Yaw
c. Tram
d. Align
e. None of the above

____ 10. Proper milling head alignment is especially important for which machining operation?

a. Precision boring
b. Turning
c. Face milling
d. Drilling
e. None of the above

____ 11. Milling head tram should be performed to within what tolerance?

a. ± 0.5"
b. ± 0.05"
c. ± 0.005"
d. ± 0.0005"
e. None of the above

____ 12. Which is the recommended tightening pattern for the milling head bolts?

a. 1-2-3-4
b. 1-3-2-4
c. 4-2-3-1
d. 1-2-4-3
e. None of the above

____ 13. Identify the term denoting a reference surface on a workpiece from which to locate other part features.

a. Datum
b. Edge
c. Pitch
d. Yaw
e. None of the above

____ 14. Which of the following is an acceptable means of moving a milling vise?

a. Die truck
b. Cart
c. Hydraulic table
d. With assistance
e. All of the above

____ 15. How close should milling vise and workpiece alignment should be performed?

a. ± 0.01"
b. ± 0.001"
c. ± 0.005"
d. ± 0.008"
e. ± 0.0005"

____ 16. Which is a measuring device used to align the milling head and work-holding accessories?

a. Dial test indicator
b. Micrometer readout
c. Protractor
d. Hermaphrodite caliper
e. None of the above

ANSWERS TO UNIT TEST

1. ab
2. c
3. a
4. d
5. b
6. ac
7. d (J3)
8. d (J3)
9. a (J3)
10. a (J3)
11. d (J3)
12. b (J3)
13. a (J4, J5)
14. e (J4)
15. b (J4, J5)
16. a (J3-5)

MODULE: MILLING

UNIT VI: SQUARING A WORKPIECE

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to install and use a standard end mill to square a workpiece mounted in a vise. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify end mill operation principles.

1.2 Mill workpiece with end mill. (competency J10, JS 1.1 and 1.2)

1.3 Square workpiece using table vise. (competency J9, JS 1.2)

1.4 Describe standards for machining a workpiece to specific dimensions.

MODULE: MILLING

UNIT VI: SQUARING A WORKPIECE

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: SQUARING WORK IN A VISE

    a. Information outline

    b. Transparency masters

    TM 1.1: End mill cutting action
    TM 1.2: Feed direction
    TM 1.3: End mill installation
    TM 1.4: Squaring work

    c. Job sheets

    JS 1.1: Install and remove an end mill
    JS 1.2: Square workpiece using table vise

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum materials

1. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

2. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

MODULE: MILLING

UNIT VI: SQUARING A WORKPIECE

LESSON 1: SQUARING WORK IN A VISE

I. End mill operation principles **(TM 1.1, 1.2)**

  A. Cutting action

    1. End cutting

    2. Side cutting

  B. Cutting and feed direction

    1. An up or conventional mill begins with a zero thickness chip and completes the cut at full thickness. It is used for most standard cutting operations.

    2. A down or climb mill begins with a full thickness chip and ends with zero thickness. It is used for machining hard or thin materials and for certain finish requirements.

II. Installing and removing an end mill

  A. Installation **(TM 1.3)**

    1. Disconnect power to the milling machine and engage the back gear. Lower the knee to permit working space, as necessary.

    2. Clean the inside of the milling spindle taper.

    3. Insert an R-8 collet into the milling spindle with the drive key aligned.

    4. Engage the drawbar thread in the top of the collet 2-3 turns.

    5. Insert the end mill into the collet and tighten with a wrench.

  B. Removal

    1. Loosen the drawbar a few turns. Threads should still be engaged, however.

    2. Hold the end mill securely and tap the top of the drawbar with a mallet. The end mill should drop from the collet.

      CAUTION: The tool will drop suddenly when the drawbar is tapped. Heavy tooling (e.g. fly cutters, boring heads, etc.) could drop quickly and injure the hand. Be prepared to support the weight of the tool when it is released. Obtain assistance as needed.

    3. Remove the collet and return to storage.

III. Principles of squaring work **(TM 1.4)**

  A. Order of sides

  B. Using end-cutting action

C. Using side-cutting action

D. Installing the work in a vise

1. Mount workpiece in the vise. If needed, use parallels to raise the surface to be machined above the top of the jaws.

2. Tighten the vise snugly.

    a. Tap the top of the workpiece to seat it in the vise.

    b. A thin strip of paper under each corner of the workpiece can be used to check that the workpiece is properly positioned in the vise.

E. In addition to maintaining the correct dimensions, squareness must also be maintained. Review the module, "Performing Precision Measurements," for methods to check squareness.

IV. Machining to dimension

A. Evaluate the tolerance requirements of the part.

1. Close tolerances require greater care.

2. A loose tolerance can be machined more quickly.

B. Perform layout.

1. Use layout dye.

2. Layout methods should be consistent with the part tolerance.

3. The lines and marks will provide rough guidelines for quick material removal.

C. Procedure for high-precision milling (± 0.001")

1. Use a high feed rate and lower speeds for fast material removal.

2. Cut to within 0.005-0.010" of the desired dimension.

    a. Measure in several places.

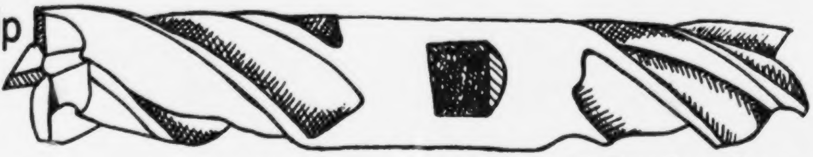
    Example: Measure all four corners of a rectangular workpiece.

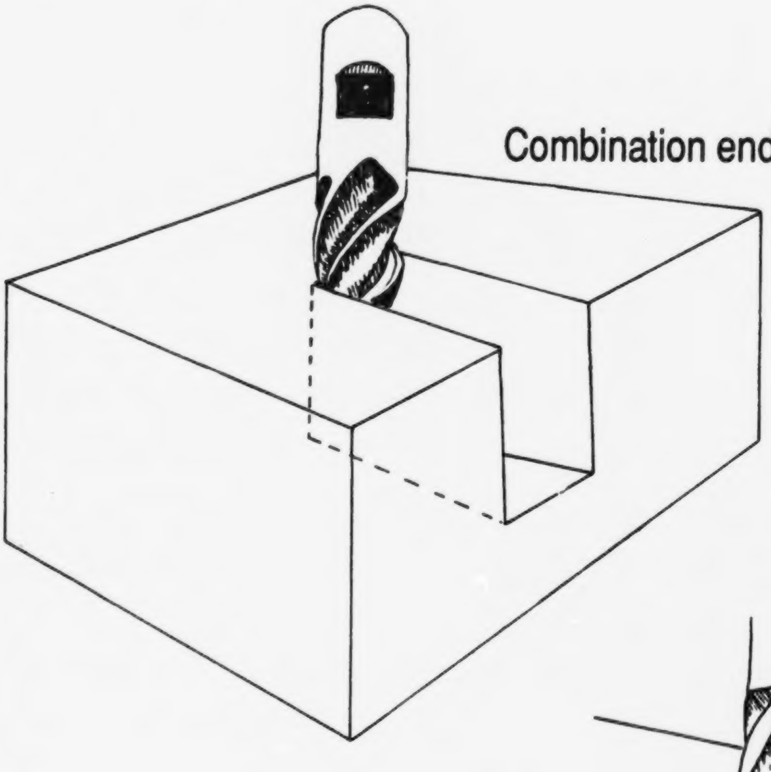
    b. Note the difference between the measurement and the desired dimension.

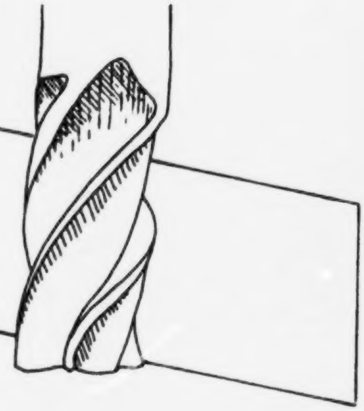
3. Carefully adjust micrometer dials to the final depth of the cut. (Generally, a finish cut requires a lower feed rate and higher speeds than roughing.)

4. Measure as above to check the final dimension. Repeat as needed.

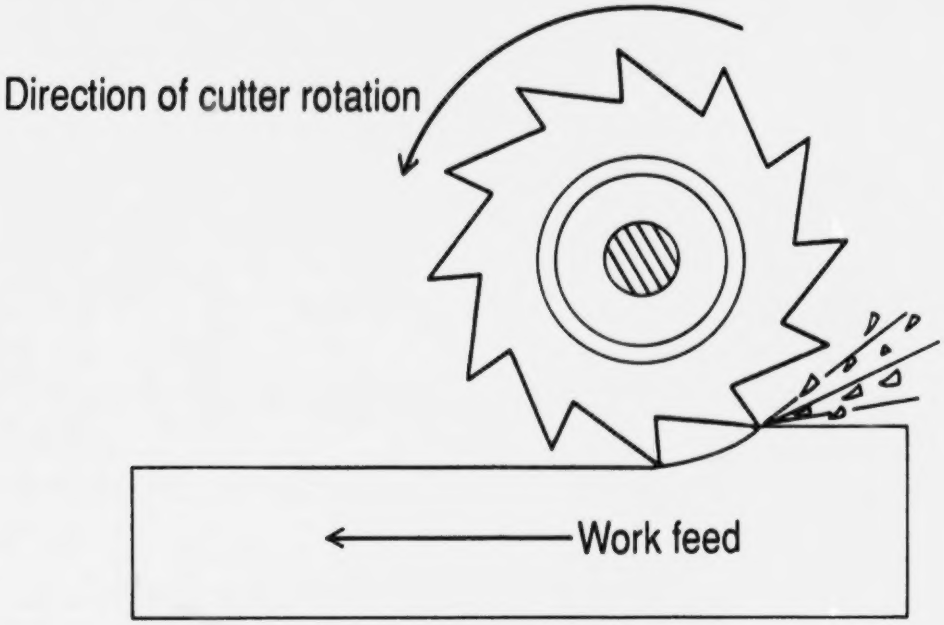
END MILL CUTTING ACTION


End cutting lip
Cutting flutes

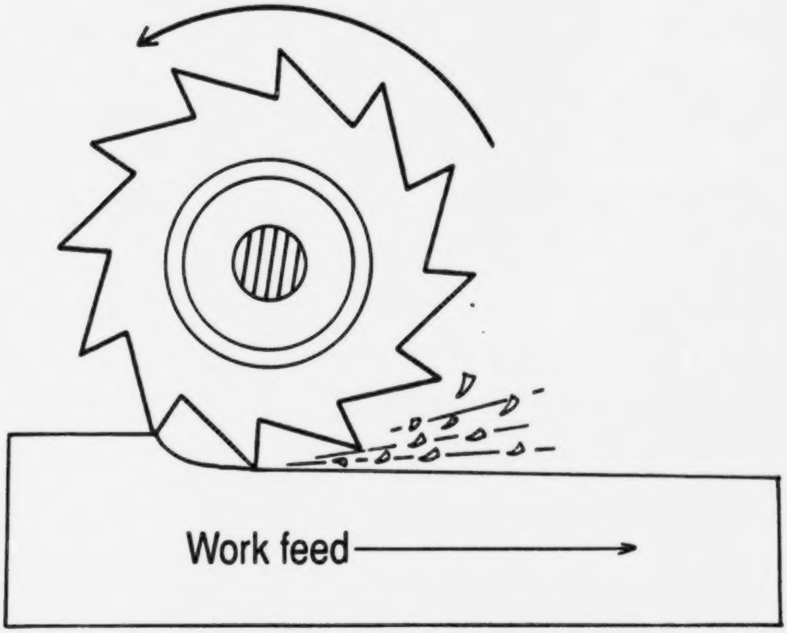

Combination end and side cutting


Side cutting only

FEED DIRECTION

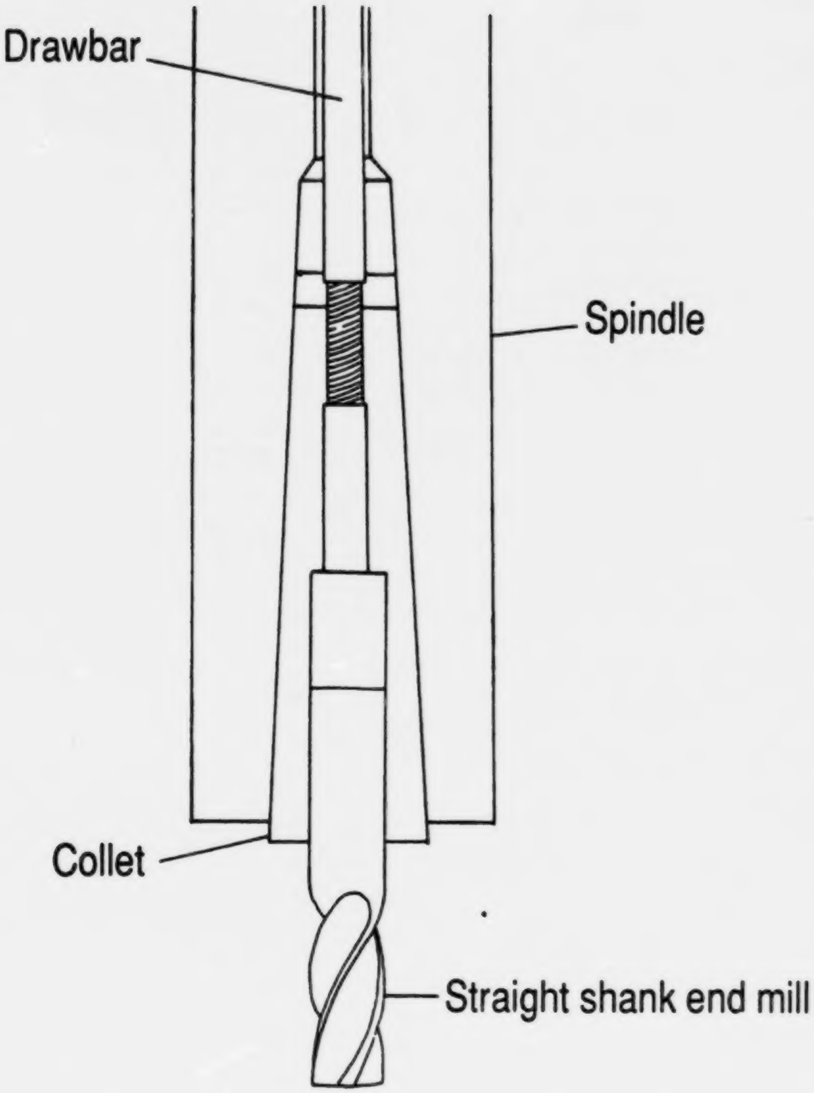

Direction of cutter rotation
Work feed

Up or conventional milling

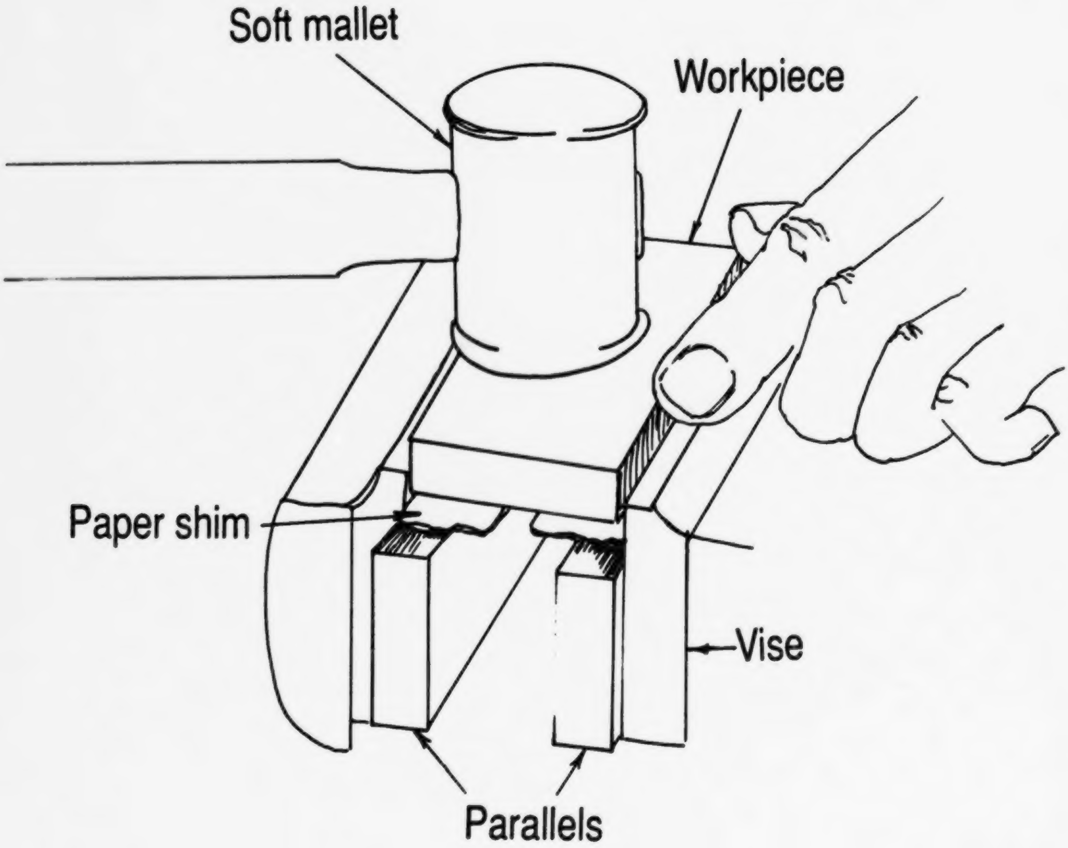


Down or climbing milling

END MILL INSTALLATION


Drawbar
Spindle
Collet
Straight shank end mill

SQUARING WORK


Soft mallet
Workpiece
Paper shim
Vise
Parallels

JS 1.1

INSTALL AND REMOVE AN END MILL

Equipment:

End mill (1/4-3/4" diameter)
R-8 collet which accommodates the end mill
Drawbar wrench
Soft mallet

Procedure:	Evaluation 3	2	1	N
Installation				
1. Disconnect power to the milling machine. Engage the back gear. Lower the knee to permit working space, as necessary.	___	___	___	___
2. Clean the inside of the milling spindle taper with a clean rag. Wipe with a finger to make sure that no grit or debris is present. Feel for the drive key.	___	___	___	___
3. Insert an R-8 collet into the milling spindle and hold. Be certain that the drive key is aligned with the keyway in the collet.	___	___	___	___
4. Turn the drawbar clockwise 2-3 turns by hand to engage the thread in the top of the collet.	___	___	___	___
5. Insert the shank of the end mill into the collet and hold. Turn the drawbar first by hand and then with a wrench until the drawbar is snug. The end mill should now be held tightly.	___	___	___	___

CAUTION: Always handle end mills and other milling cutters with a rag or shop towel to avoid being cut.

Removal				
6. To remove the end mill, loosen the drawbar (counterclockwise) a few turns. The threads should still be engaged, however.	___	___	___	___
7. Hold the end mill securely with a rag or shop towel and tap the top of the drawbar with a mallet. The end mill should drop from the collet.	___	___	___	___

CAUTION: The tool will drop suddenly when the drawbar is tapped. Heavy tooling (e.g. fly cutters, boring heads, etc.) can drop quickly and injure the hand. Be prepared to support the weight of the tool when it is released. Obtain assistance, as needed.

8. Remove the collet and return to storage.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is one-half the student's evaluation for competency J10: Mill workpiece with end mill.

JS 1.2

SQUARE WORK USING TABLE VISE

Equipment:

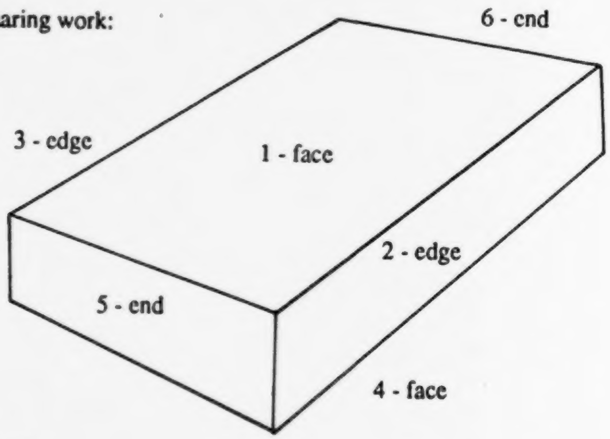
End mill (1/4-3/4" diameter)
R-8 collet which accommodates the end mill
Drawbar wrench
Soft mallet
6" vernier caliper
Small strips of paper (4)
Rectangular workpiece to be machined according to the instructor's dimensions
Swivel-base milling vise

CAUTION: Always turn off the spindle and wait for it to come to a complete stop before making any adjustments or measurements.

	Evaluation			
Procedure:	3	2	1	N
1. Disconnect power to the milling machine. Engage the back gear. Lower the knee to permit working space, as necessary.	___	___	___	___
2. Perform daily lubrication. Align the head and vise, as needed.	___	___	___	___
3. Mount the collet and end mill in the spindle. Set the correct spindle speed.	___	___	___	___
4. Prepare the workpiece by removing burrs and wiping off any chips or dirt.	___	___	___	___
5. Mount the workpiece securely in the vise with the first broad surface facing up. Use parallels, as necessary.	___	___	___	___
6. With the end mill stationary, raise the knee up until the end mill just contacts the top of the workpiece. This can be determined by slowly moving a strip of notebook paper under the cutter until it is pinched between the cutter and the workpiece.	___	___	___	___
7. Move the cutter to the side and set the depth for a rough cut by raising the knee. Turn on the spindle. Lock all motion except the longitudinal. Advance the cutter into the workpiece by hand and engage the power feed. Cut at the same depth across the entire workpiece using either a back-and-forth or spiral pattern.	___	___	___	___
8. Measure the workpiece in the vise.	___	___	___	___
9. Set the depth for a finish cut. Adjust the speed and feed, as needed. Execute the finish cut as above. Measure the workpiece.	___	___	___	___

10. Identify the first edge to be machined. Place this edge up in the vise with the machined broad surface against the stationary jaw. Place a 1/2" diameter rod between the other broad face and the movable jaw; clamp as shown in the illustration. Seat the workpiece in the vise with a mallet. _ _ _ _

Order of sides for squaring work:



11. Machine as described above. _ _ _ _

12. Reverse the workpiece and machine the second edge. Use paper under the edge just machined to ensure that the workpiece is seated in the vise. Keep the machined face against the fixed jaw. When machining this surface, be careful to achieve the desired final width dimension. _ _ _ _

13. Turn the workpiece up in the vise to machine surface #4 or the second broad surface. Use parallels and paper strips to be sure that the workpiece is properly seated. Leave one end protruding 1/4-1/2" from the end of the vise. Machine the face as described above. Be careful to achieve the desired final thickness. _ _ _ _

14. Machine the end protruding from the vise using a side-cutting action of the end mill. _ _ _ _

15. Turn the workpiece end for end and machine surface #6 or the second edge. Be careful to obtain the correct dimension. _ _ _ _

NOTE: After each surface is machined and the workpiece is removed from the vise, it is necessary to completely remove any burrs made by machining. Also, clean the vise surface and remove any debris before placing the workpiece back in the vise.

16. Remove workpiece from the vise. Remove the cutting tool. Clean the vise, removing chips, oil and debris. _ _ _ _

Average of above evaluations* _ _ _ _

*This average the completes the student's evaluations for competencies J9 and J10.

MODULE: MILLING

UNIT VI: SQUARING A WORKPIECE

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which cutting actions can be achieved with an end mill?

- a. End and side cutting
- b. End and serrated cutting
- c. Side and reciprocating action
- d. Round and side cutting
- e. None of the above

____ 2. Which is true of a workpiece in conventional milling?

- a. Moves in the same direction as cutter rotates
- b. Moves against the rotation of the cutter
- c. Remains stationary and the cutter moves across it
- d. Workpiece and cutter move with each other
- e. None of the above

____ 3. Which is a standard milling cutter holder for vertical milling?

- a. Jacobs chuck
- b. Type C arbor
- c. Type A arbor
- d. Type B arbor
- e. R-8 collet

____ 4. Which is a device which holds a collet in the milling spindle?

- a. Collet clamp
- b. Set screw
- c. Arbor support
- d. Drawbar
- e. None of the above

____ 5. How is a collet released from the spindle taper?

- a. Grasp it with adjustable locking pliers.
- b. Tap the top of the drawbar lightly.
- c. Release the collet clamp.
- d. Remove the arbor support.
- e. All of the above

____ 6. When squaring a workpiece, what is the correct order of sides?

- a. Broad surface, edge, edge, broad surface, end, end
- b. Edge, edge, end, end, broad surface, broad surface
- c. End, edge, broad surface, end, edge, broad surface
- d. End, edge, end, broad surface, edge, broad surface
- e. None of the above

____ 7. How does a machinist check for the correct seating of a workpiece in a vise?

a. With a feeler gage
b. By placing a small strip of paper under each corner
c. By feeling the edge of the workpiece
d. By adjusting the vise base
e. All of the above

____ 8. How should end mills and other cutting tools be held while tightening the drawbar?

a. With a rag
b. With gloves
c. With tool tongs
d. With the bare hand
e. None of the above

____ 9. What should be done when setting up the milling machine?

a. Safety glasses must be worn.
b. The power to the mill should be disconnected.
c. Work surfaces must be wiped clear of debris.
d. The workpiece must be free from burrs.
e. All of the above

____ 10. What should be done with a machining axis is not being used in machining?

a. Remove it
b. Lock it
c. Rotate it
d. Lower it clear of the area
e. None of the above

____ 11. Which is a true statement regarding roughing cuts?

a. Use relatively low speeds and high feed rates for quick material removal.
b. Leave 0.005-0.010" for the finishing cut.
c. Check the measurement after the roughing cut.
d. All of the above
e. None of the above

____ 12. Which of the following must be done before attempting to square a workpiece held in a vise?

a. The milling head must be aligned.
b. The vise must be aligned to the column.
c. The vise surface must be wiped clean.
d. All of the above
e. None of the above

ANSWERS TO UNIT TEST

1. a (J10)
2. b (J10)
3. e (J10)
4. d (J10)
5. b (J10)
6. a (J9)
7. b (J9)
8. a (J10)
9. e (J10)
10. b (J10)
11. d (J10)
12. d (J9)

MODULE: MILLING

UNIT VII: HOLE-MAKING OPERATIONS

UNIT OBJECTIVE

Upon completion of this unit, the student should be able to locate hole centers with an edge finder; operate digital readouts; and drill, ream and bore holes in workpieces using a vertical milling machine. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

After completion of the lessons in this unit, the student should be able to:

1.1 Identify the principles of precision hole-making.

1.2 Locate work with edge finder. (competency J11, JS 1.1)

1.3 Use digital readout. (competency J23, JS 1.2)

1.4 Drill holes with a milling machine. (competency J12, JS 1.3)

1.5 Ream holes with a milling machine. (competency J13, JS 1.3)

2.1 Identify the reasons for using a boring head.

2.2 Identify the parts of typical boring head kit.

2.3 Bore holes with milling machine (competency J14, JS 2.1)

MODULE: MILLING

UNIT VII: HOLE-MAKING OPERATIONS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: LOCATING HOLE CENTERS, DRILLING AND REAMING

   a. Information outline

   b. Job sheets

      JS 1.1: Locate work with edge finder
      JS 1.2: Use digital readout
      JS 1.3: Drill and ream holes with milling machine

2. Lesson 2: USING A BORING HEAD

   a. Information outline

   b. JS 2.1: Bore holes with milling machine

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. McCarthy, Willard J., and Victor E. Repp. Machine Tool Technology. 4th ed. Bloomington, IL: McKnight Publishing Co., 1979.

2. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

3. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guides/materials

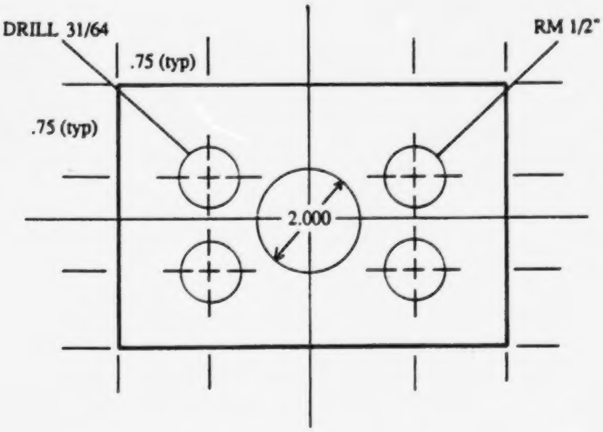
1. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

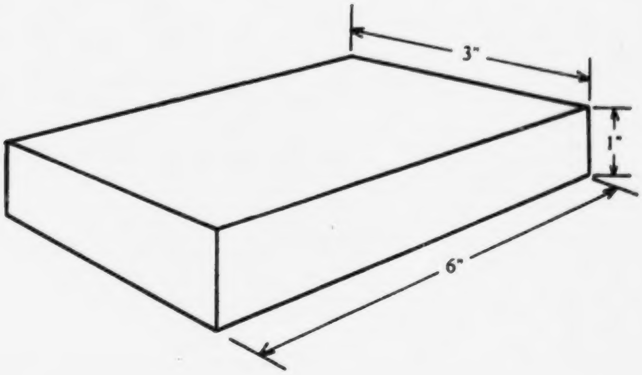
2. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. The following workpiece is used as a sample for all job sheets in this unit. Any similarly sized workpiece may be used instead, at the instructor's discretion.


DRILL 31/64
RM 1/2"
.75 (typ)
.75 (typ)
2.000



MODULE: MILLING

UNIT VII: HOLE-MAKING OPERATIONS

LESSON 1: LOCATING HOLE CENTERS, DRILLING AND REAMING

I. Principles of precision hole machining

   A. Centers must be located accurately.

   B. The machine must be clean and properly aligned.

   C. Consider geometric tolerances.

      1. Parallelism

      2. Cylindrical aspects

      3. Perpendicularity

      4. Location and diameter (circular tolerance zone)

   D. Layout

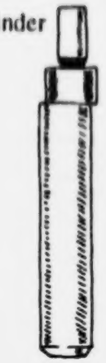
      1. Square the work surface. Identify datum plane of reference.

      2. Do the layout as accurately as possible to provide a guide for the machine layout.

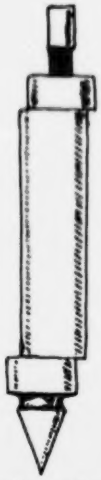
II. Edge finder

   A. The edge finder accurately locates the edge or datum reference surface by jumping off center.

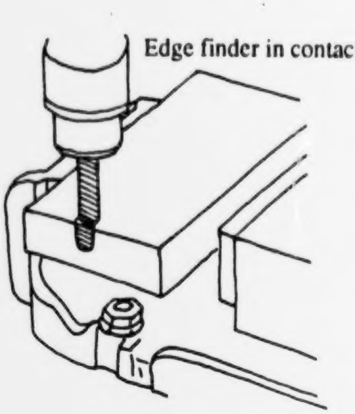
   B. Use edge finders with micrometer dials or DROs.



Standard edge finder



Double-end edge finder with center finder



Edge finder in contact with work

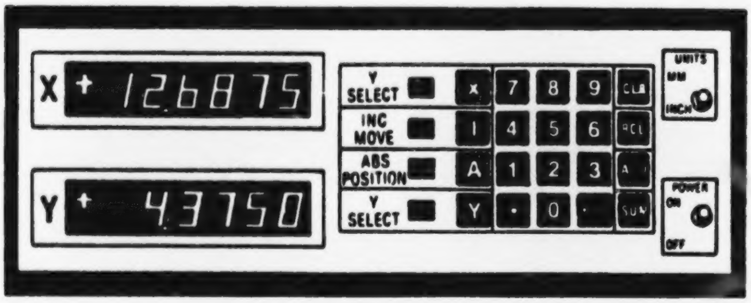
III. Micrometer dials and digital readouts

  A. Micrometer dials aid in accurate location of hole centers.

    1. Zero dials for each hole.

    2. Be aware of backlash--measure only in one direction. (Backlash is the ineffective or wasted motion when a screw's direction of rotation is reversed.)

  B. Digital readout (DRO)


X
+ 12.6875
Y
+ 4.3750
Y SELECT
INC MOVE
ABS POSITION
Y SELECT
X
7
8
9
CLR
I
4
5
6
RCL
A
1
2
3
A
Y
·
0
·
SUM
UNITS
MM
INCH
POWER
ON
OFF

    1. DRO replaces micrometer dials with electronic replacements.

    2. DRO permits zero reset and accumulation of position data for datum referencing.

    3. Error from backlash reading is reduced since DRO reads only actual table movement.

    4. Baseline or tabular coordinate dimensioning permits direct reading of hole locations from the drawing.

IV. Drilling and reaming using the vertical mill

  A. Drill press operations on the mill

    1. All drill press operations

    2. Greater accuracy in location and straightness

  B. Procedure

    1. Follow standard drill press practices.

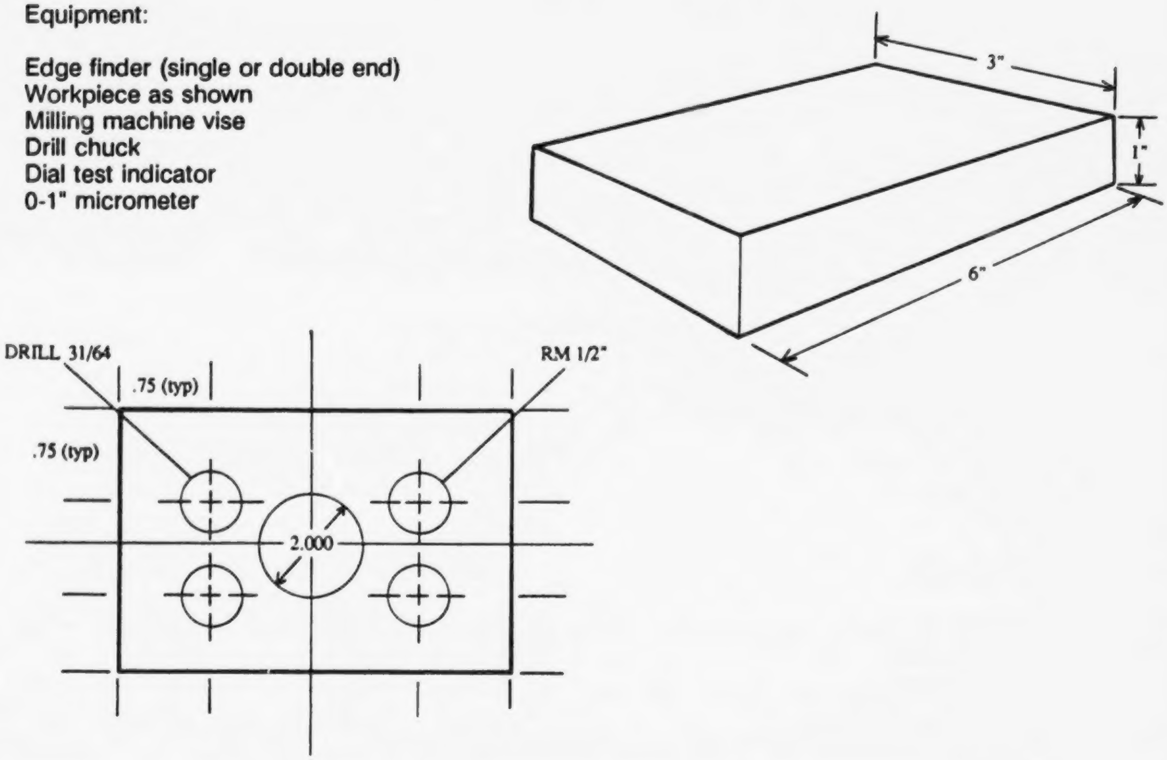
    2. Check machine alignment before proceeding.

    3. Lower the knee to remove and install cutting tools.

LOCATE WORK WITH EDGE FINDER

Equipment:

Edge finder (single or double end)
Workpiece as shown
Milling machine vise
Drill chuck
Dial test indicator
0-1" micrometer



	Evaluation			
Procedure:	3	2	1	N
1. Thoroughly clean the milling machine table. Sweep with the indicator and adjust the alignment, as necessary. Mount the milling machine vise and align the fixed jaw with the column.				
2. Install the drill chuck in the spindle. Using the micrometer, measure and note the diameter of the edge finder end. Install the edge finder in the drill chuck.				
3. On the workpiece, identify the datum reference surface for hole location measurements. Mount the work in the vise so that this surface can be approached with the edge finder. Support the work on parallels so that the bottom of the vise will not be damaged during drilling.				
4. Turn on the spindle and set at about 500 rpm. Move the table to position the edge finder near the workpiece. Position the edge finder about 1/4" below the top of the workpiece.				
5. Move the table in the longitudinal axis until the edge finder touches the workpiece and jumps off center. Set the micrometer dial at zero and back the edge finder away from the workpiece one complete turn of the table handwheel.				

6. Approach the workpiece again. As the zero point on the micrometer dial is approached, move in one-thousandth inch increments. The edge finder should jump off center at exactly the point that the micrometer dial reads zero. If it does not, reset the zero on the micrometer dial and repeat. Turn off the spindle. ___ ___ ___ ___

7. Raise the edge finder above the level of the workpiece and move it towards the workpiece one-half of the edge-finder diameter. The center of the edge finder and the machine spindle are now directly over the edge of the workpiece. Move the required distance in the longitudinal axis. ___ ___ ___ ___

8. Repeat steps 4-7 for the transverse axis. The spindle is now positioned above the hole center location. ___ ___ ___ ___

9. Continue around the workpiece and the other hole centers. Be aware of screw backlash. Relocate the edge with the edge finder, as needed. ___ ___ ___ ___

10. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

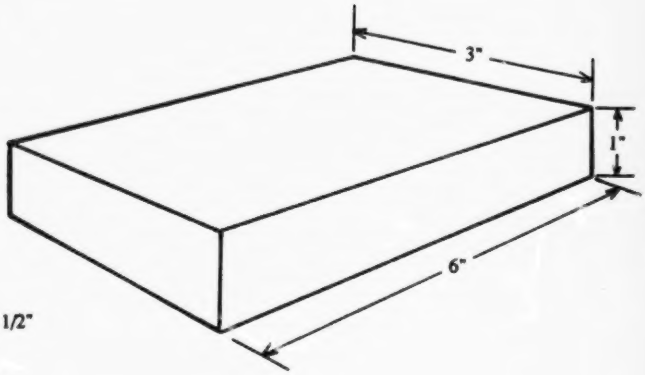
*This average is the student's final evaluation for competency J11: Locate work with edge finder.

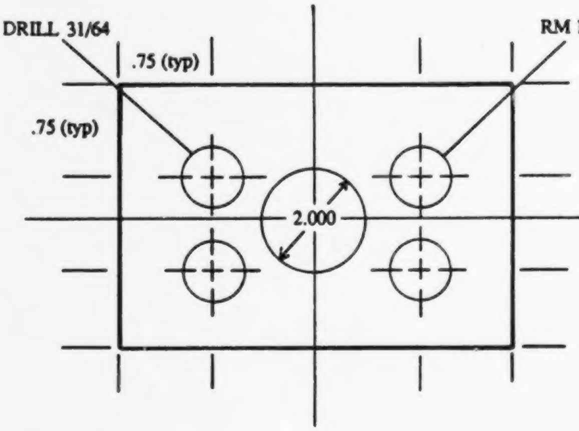
JS 1.2

USE DIGITAL READOUT

Equipment:

Milling machine with two-axis DRO unit
Edge finder (single or double end)
Workpiece as shown
Milling machine vise
Drill chuck
Dial test indicator
0-1" micrometer





Procedure:	Evaluation 3	2	1	N
1. Thoroughly clean the milling machine table. Sweep with the indicator and adjust the alignment, as necessary. Mount the milling machine vise and align the fixed jaw with the column.	___	___	___	___
2. Install the drill chuck in the spindle. Using the micrometer, measure and note the diameter of the edge finder end. Install the edge finder in the drill chuck.	___	___	___	___
3. On the workpiece, identify the datum reference surface for hole location measurements. If necessary, create a sketch of the hole layout in baseline-dimensioned form. Mount the workpiece in the vise so that this surface can be approached with the edge finder. Support the workpiece on parallels so that during drilling the bottom of the vise will not be damaged.	___	___	___	___
4. Turn on the spindle and set at about 500 rpm. Move the table to position the edge finder near the workpiece. Position the edge finder about 1/4" below the top of the workpiece. Turn on the digital readout and set the X- and Y-axes to zero.	___	___	___	___

5. Move the table with the X-axis until the edge finder touches the workpiece and jumps off center. Set the DRO X-axis at zero and back the edge finder away from the workpiece one complete turn of the table handwheel. _ _ _ _

6. Approach the workpiece again. As the zero point on the DRO is approached, move in one-thousandth inch increments. The edge finder should jump off center at exactly the point at which the DRO reads zero. If it does not, reset the zero and repeat. Turn off the spindle. _ _ _ _

7. Raise the edge finder above the level of the workpiece and move it towards the workpiece one-half of the edge finder diameter. The center of the edge finder and the machine spindle are now directly over the edge of the workpiece. Reset the zero again. Move the required distance in the X-axis. _ _ _ _

8. Repeat steps 4-7 for the transverse axis. The spindle is now positioned above the hole center location. _ _ _ _

   NOTE: Do not move the table to remove and install cutting tools because hole locations will be lost. Instead, raise and lower the knee.

9. Continue around the workpiece and locate the other hole centers. Disregard screw backlash since the DRO will only read actual table movement. Accumulate dimensions to locate remaining holes if absolute dimensioning is used. Reset the zero after each location if dimensioning is incremental. _ _ _ _

10. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials. _ _ _ _

Average of above evaluations* _ _ _ _

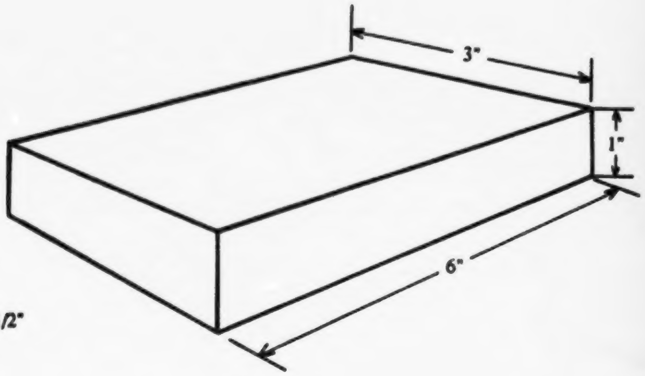
*This average is the student's final evaluation for competency J23: Use digital readout.

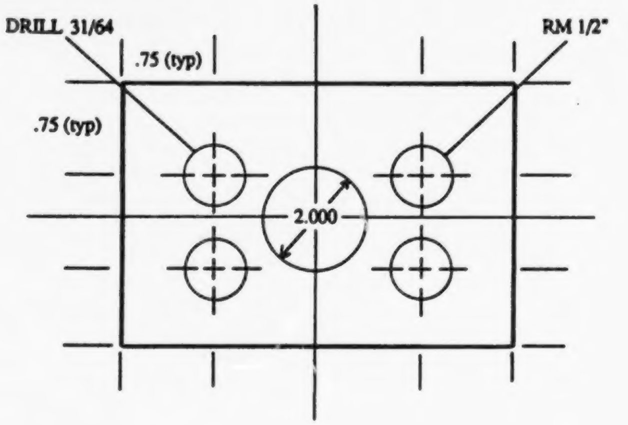
JS 1.3

DRILL AND REAM HOLES WITH MILLING MACHINE

Equipment:

#3 center drill
1/4" HSS drill
31/64" HSS drill
1/2" HSS chucking reamer
Edge finder (single or double end)
Workpiece as shown
Milling machine vise
Drill chuck
Dial test indicator
0-1" micrometer





Procedure:	Evaluation 3	2	1	N
1. Thoroughly clean the milling machine table. Sweep with the indicator and adjust the alignment, as necessary. Mount the milling machine vise and align the fixed jaw with the column.	_	_	_	_
2. Install drill chuck in the spindle. Using the micrometer, measure and note the diameter of the edge finder end. Install edge finder in the drill chuck.	_	_	_	_
3. On the workpiece, identify the datum reference surface for hole location measurements. Mount the workpiece in the vise so that this surface can be approached with the edge finder. Support the workpiece on parallels so that during drilling the bottom of the vise will not be damaged.	_	_	_	_
4. Turn on the spindle and set at about 500 rpm. Move the table to position the edge finder near the workpiece. Position the edge finder about 1/4" below the top of the workpiece.	_	_	_	_
5. Move the table with the longitudinal axis until the edge finder touches the workpiece and jumps off center. Set the micrometer dial at zero and back the edge finder away from the workpiece one complete turn of the table handwheel.	_	_	_	_

6. Approach the workpiece again. As the zero point on the micrometer dial is approached, move in one-thousandth inch increments. The edge finder should jump off center at exactly the point at which the micrometer dial reads zero. If it does not, reset the zero on the micrometer dial and repeat. Turn off the spindle. ___ ___ ___ ___

7. Raise the edge finder above the level of the workpiece and move it towards the workpiece one-half of the edge finder diameter. The center of the edge finder and the machine spindle are now directly over the edge of the workpiece. Move the required distance in the longitudinal axis. ___ ___ ___ ___

8. Repeat steps 4-7 for the transverse axis. ___ ___ ___ ___

9. With the spindle positioned above the hole center location, remove the edge finder and insert the cutting tools in the following order: #3 center drill, 1/4" drill (pilot drill), 31/64" drill and 1/2" chucking reamer. ___ ___ ___ ___

   NOTE: Calculate and set the appropriate spindle rpm for the tools listed. Use the quill lever to raise and lower the tools, as required.

10. After completing the first hole, continue around the workpiece and complete the other holes. Be aware of screw backlash. Relocate the edge with the edge finder, as needed. ___ ___ ___ ___

11. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

*This average is the student's final evaluation for competencies J12 and J13.

MODULE: MILLING

UNIT VII: HOLE-MAKING OPERATIONS

LESSON 2: USING A BORING HEAD

I. Reasons for using a boring head

  A. It produces large holes which are not possible with drilling.

  B. It produces holes with extremely accurate dimensions with respect to diameter, straightness, cylindrical aspects and perpendicularity.

  C. Pre-drilling a hole provides a point of entry for the boring bar.

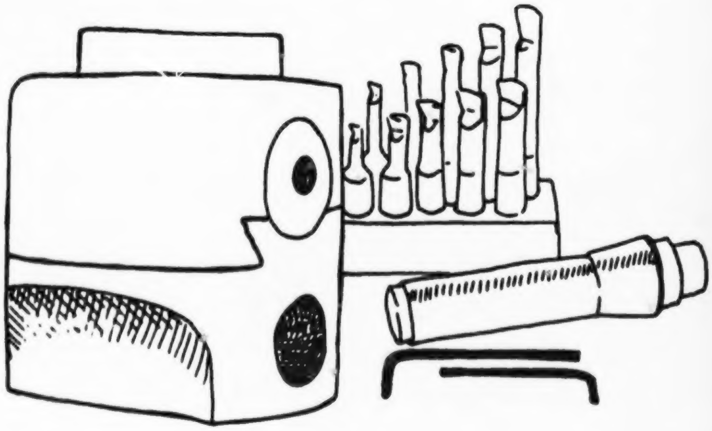
II. Parts of a typical boring head kit

  A. Boring head

    1. Micrometer adjustment

    2. Locking screw

    3. Boring bar holes



  B. Shank

  C. Boring bars

  D. HSS toolbits with typical lathe tool geometry

III. Procedure

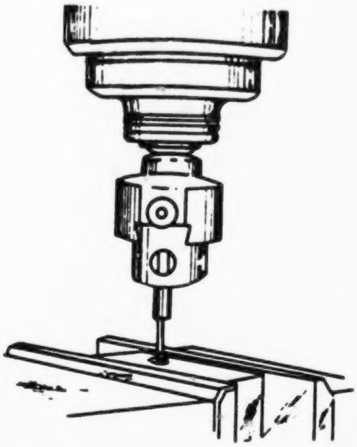
  A. Locate the hole center as for drilling.

  B. Center drill and drill the starting hole.

  NOTE: The starting hole must be large enough to accommodate the smallest boring bar (seldom less than 1/2").

  C. Set the quill power feed at 0.003" per revolution. Calculate and set the rpm to achieve the recommended surface cutting speed for the material.

  D. Adjust the boring head until the boring tool just touches the inside of the hole wall. Withdraw the tool and set for a 0.020" cut depth.



E. Complete the cut and measure. Repeat.

F. For the finish pass, set the feed at 0.0015" per revolution and set the depth to achieve the desired final dimension. Make trial cuts and measurements on a small section at the top of the hole until the desired dimension is achieved. Complete the cut.

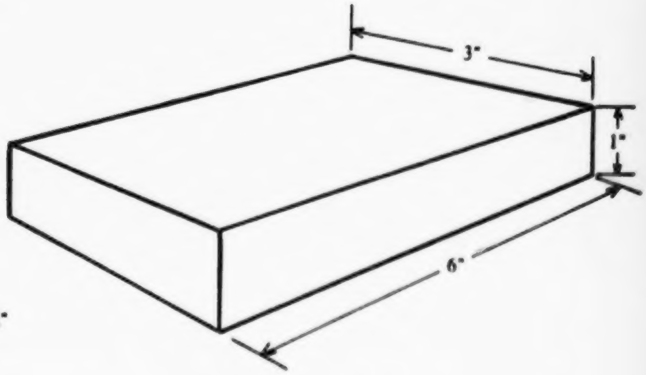
G. Adjust the boring head to a non-contact position before withdrawing after the final pass. This will prevent scoring of the interior surface of the hole.

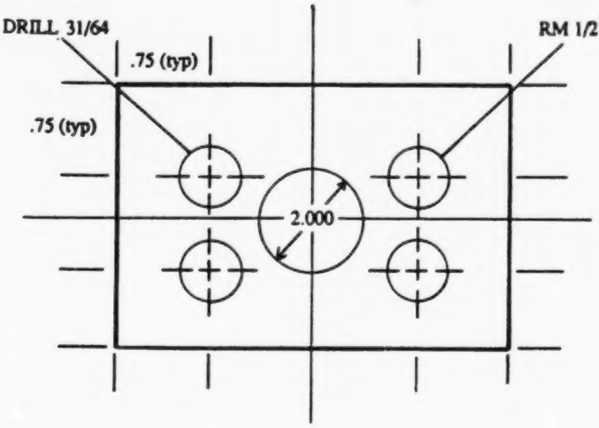
JS 2.1

BORE HOLES WITH MILLING MACHINE

Equipment:

Telescoping hole gage set
1-2" micrometer
Edge finder (single or double end)
Workpiece as shown
Milling machine vise
Drill chuck
Dial test indicator
0-1" micrometer
Boring head kit





Procedure:	Evaluation 3	2	1	N
1. Test the machine head and vise alignment with the dial test indicator and correct as needed.	__	__	__	__
2. Locate the hole center with the edge finder. Lock table and saddle movement.	__	__	__	__
3. Drill a starting hole that is 1/2" in diameter. Use additional drills as available to drill a hole that is within 1/8" of the desired dimension.	__	__	__	__
4. Install an appropriately sized boring tool in the milling spindle.	__	__	__	__
5. Adjust the boring head until the tool just touches the inner surface of the hole. Withdraw the tool and set the boring head for a cutting depth of 0.020".	__	__	__	__
NOTE: Do not move the table to position the boring head because the hole center location will be lost.				
6. Set the power feed at 0.003" per revolution. Using the appropriate cutting speed for the boring tool, calculate and set the rpm.	__	__	__	__

7. Start the machine and engage the power feed. Allow the bar to cut 1/8" into the hole. Withdraw the tool and turn the machine off. Measure using a telescoping hole gage and micrometer. If the hole is not oversized, continue. Repeat until it is within 0.010-0.015" of the desired dimension. ___ ___ ___ ___

8. Adjust the boring head for the final dimension. Set the feed rate at 0.0015" per revolution. ___ ___ ___ ___

9. Start the machine and engage the feed. Allow the tool to cut to a depth of 1/8". Measure. Adjust the depth of cut as needed to achieve the final dimension within tolerance. ___ ___ ___ ___

10. When the cut is complete, adjust the boring tool so that it will not touch the hole wall. This will prevent scoring of the wall when the tool is withdrawn. ___ ___ ___ ___

11. Clean up area and return tools and materials. ___ ___ ___ ___

Average of above evaluations* ___ ___ ___ ___

*This average is the student's final evaluation for competency J14: Bore holes with milling machine.

MODULE: MILLING

UNIT VII: HOLE-MAKING OPERATIONS

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which is not an important consideration in precision hole machining?

a. Apply geometric tolerances appropriately.
b. Clean and properly align the machine.
c. Use proper feeds and speeds.
d. Accurately locate the centers.
e. Mark workpiece for rough layout.

____ 2. What purpose does accurate layout before precision hole machining serve?

a. Provides marks for the center punch
b. As a general guide that holes are positioned accurately
c. Does not require datum identification
d. Can be performed without instruments
e. Not necessary

____ 3. Define the term backlash.

a. Deflection of the workpiece against the rotation of a cutter
b. Deflection of the cutter against an immovable object
c. Rotary motion of a screw
d. Ineffective or wasted motion when a screw's direction of rotation is reversed
e. Sudden loss of machining power

____ 4. How does a digital readout reduce backlash error?

a. It reads only actual table movement.
b. It is equipped with high-tech sensory capabilities.
c. It reads in 0.0001" units.
d. It is the most accurate measuring device today.
e. There is not a requirement for reading a dial.

____ 5. Which dimensioning system is particularly suited to use with a digital readout?

a. Metric
b. Baseline
c. Incremental
d. English
e. None of the above

____ 6. Which device helps accurately locate holes on a milling machine?

a. Vernier caliper
b. Steel rule
c. Center punch
d. Prick punch
e. Micrometer dial

____ 7. What happens to signal the operator that the edge finder has contacted the workpiece?

a. The machine spindle stops.
b. The edge finder end jumps off center.
c. A red light flashes.
d. Longitudinal motion stops.
e. None of the above

____ 8. To install and remove cutting tools when locating and machining holes, what should the operator do?

a. Review the instruction manual for the particular machine.
b. Lower or raise the knee as needed.
c. Swivel the vise, if possible.
d. Move only the transverse axis of the machine.
e. Use a spanner wrench.

____ 9. What is helpful to do when using a digital readout to locate holes?

a. Create a baseline-dimensioned sketch of the part.
b. Use only round datum references.
c. Note hole circumferences for calculation.
d. Install a keyless drill chuck.
e. None of the above

____ 10. Why would an operator set a digital readout to zero after locating the edge?

a. To improve the cutting tool performance
b. So the operator can use the edge as an absolute reference origin
c. For metric dimensioning only
d. To correct many adjustments
e. None of the above

____ 11. Why is it necessary to drill a hole before boring?

a. To provide an entry point for the boring bar
b. To prevent scoring of the hole wall
c. To provide adequate lubricant dispersal
d. To permit the operator to see the tool in action
e. None of the above

____ 12. Which of the following is a good per-revolution quill feed setting for rough boring?

a. 0.0012"
b. 0.0015"
c. 0.003"
d. 0.030"
e. 0.050"

____ 13. What is a good per-revolution feed for finish cutting with a boring head?

a. 0.0001"
b. 0.0015"
c. 0.003"
d. 0.030"
e. 0.050"

____ 14. What should the operator do to prevent scoring of the workpiece after the final pass?

a. Adjust the bar so that it will not contact the work when withdrawn.
b. Call for a quality inspection.
c. Withdraw the tool very slowly.
d. Preset all adjustments.
e. None of the above

____ 15. Which of the following would not be found in a typical boring head kit?

a. Boring head
b. Twist-drill tool bits
c. Shank
d. Boring bars
e. Locking screw

ANSWERS TO UNIT TEST

1.	e	(J12-14)
2.	b	(J11)
3.	d	(J11)
4.	a	(J23)
5.	b	(J23)
6.	e	(J11)
7.	b	(J11)
8.	b	(J12-14)
9.	a	(J23)
10.	b	(J23)
11.	a	(J14)
12.	c	(J14)
13.	b	(J14)
14.	a	(J14)
15.	b	(J14)

MODULE: MILLING
UNIT VIII: FORM MILLING

UNIT OBJECTIVE

In this unit the student will learn about various types of form milling cutters and will use a radius milling cutter to form a radius on the corner of a workpiece. This knowledge will be evidenced by achieving the specified score on the job sheet and unit test.

SPECIFIC OBJECTIVES

Upon completion of the lessons in this unit, the student should be able to:

1.1 Identify form milling applications.

1.2 Describe special considerations for form milling.

1.3 Identify tools used for measuring forms.

1.4 Form mill a workpiece. (competency J15, JS 1.1)

MODULE: MILLING

UNIT VIII: FORM MILLING

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plan

    1. Lesson 1: FORM MILLING

        a. Information outline

        b. Job sheet

            JS 1.1: Form mill workpiece

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

2. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guides/materials

1. Apprentice Machinist (AFSC 53130). Vol. I. Machine Shop Fundamentals. Gunter Air Force Base, AL: Extension Course Institute, Air University, 1981.

2. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

3. Benson, Robert T., and Margaret R. Gregory. V-TECS Guide for Machine Shop. Columbia, SC: South Carolina Department of Education, 1985.

4. Dunn, James. Machine Shop I. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1981.

5. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

6. Grimes, L. Machinist. Austin: Center for Occupational Curriculum Development, University of Texas at Austin, 1982.

7. Yettaw, Jerome. Vocational Machine Shop. University of Missouri-Columbia: Instructional Materials Laboratory, 1977.

C. Other references

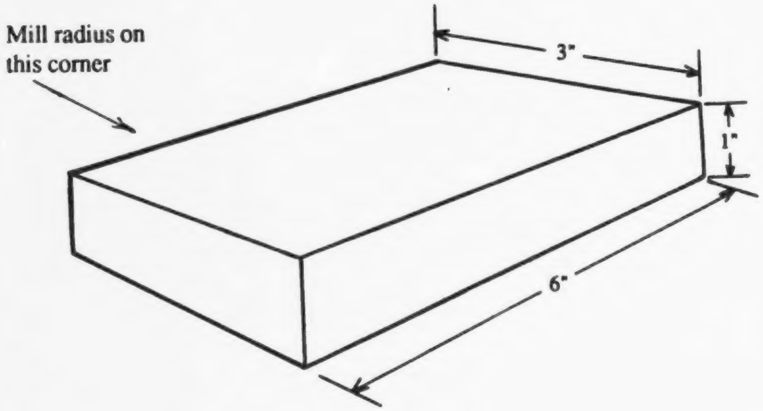
1. "1983 Mechanical Drives Reference Issue." Machine Design 30 June 1983.

2. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Workpiece for this unit can be the same as that used in Unit VII.



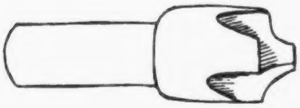
MODULE: MILLING

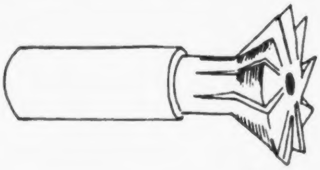
UNIT VIII: FORM MILLING

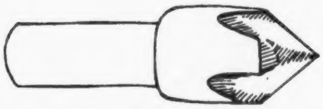
LESSON 1: FORM MILLING

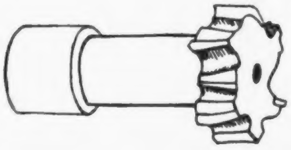
I. Form milling

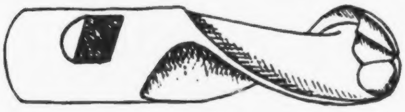
A. Makes use of a specially shaped milling cutter to create a form or shape in the workpiece

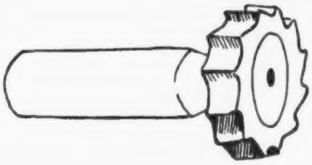

Radius


Dovetail


Chamfer


T-slot


Ball-nose


Woodruff keyway

B. Radius end mill--for cutting a radius on the corner of a workpiece

C. Chamfer end mill--cuts a 45° chamfer on the corner of a workpiece

D. Ball-nose end mill--cutter with a round end used to cut a concave groove

II. Important considerations

A. Blending

1. On radius and chamfer cutters, upper and lower portions must be carefully blended into the top and side of the workpiece.

2. Use layout die to check for contact with work surface.

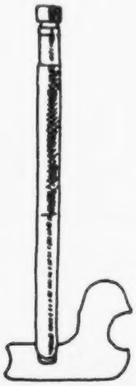
B. Speeds and feeds

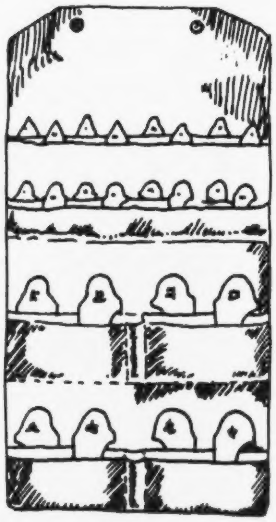
1. Flutes on form milling cutters are often not as deep as on standard end mills and can become loaded quickly.

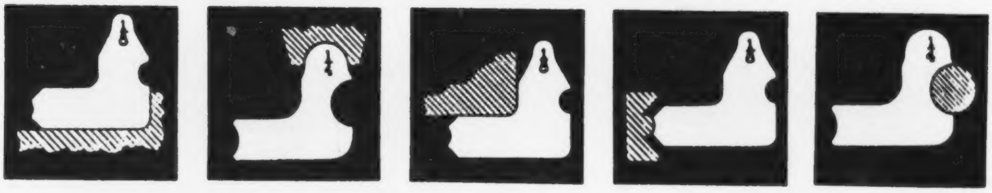
2. Operate at lower speeds and slower feeds (approximately 75% of the calculated speeds and feeds for standard cutters of the same diameter).

III. Measuring forms

A. Radius--use radius gages







B. Chamfer--use steel rule or vernier caliper

C. Concave--use radius gages

IV. General procedure (radius milling)

A. Identify workpiece material.

B. Mount and align vise.

C. Select and mount form milling cutter.

D. Secure and align workpiece.

E. Select and set spindle speed and feed.

F. Touch off tool on top and side of workpiece and note reading necessary for finish cut.

G. Make preliminary cut.

H. Check workpiece against specification.

I. Finish cut to final dimension.

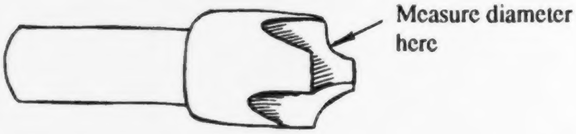
JS 1.1

FORM MILL WORKPIECE

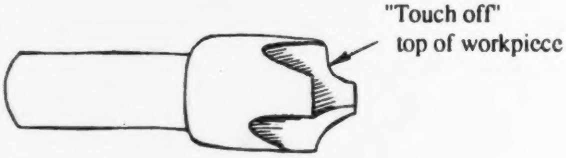
Equipment:

Layout dye
1/2" radius cutter
Radius gages
Milling vise
Parallels
Steel rule
0-1" micrometer

Procedure:	Evaluation 3	2	1	N
1. Disconnect power to milling machine. Engage back gear. Lower knee to permit working space as necessary.	___	___	___	___
2. Perform daily lubrication. Align head and vise as needed.	___	___	___	___
3. Prepare workpiece by removing burrs and wiping clean of chips and dirt.	___	___	___	___
4. Coat edge and surface at corner to be cut with layout dye.	___	___	___	___
5. Mount workpiece securely in vise. Use parallels as necessary. Corner to be machined should be parallel with longitudinal travel of table. Cutting will be accomplished by transverse and knee movement.	___	___	___	___
6. Measure bottom diameter of cutter with micrometer and note this dimension.	___	___	___	___



7. Locate edge of workpiece with edge finder. Zero transverse micrometer dial. Select form milling cutter. Mount collet and cutter in spindle. Set proper spindle speed.	___	___	___	___



8. Touch off top inside surface of cutter to locate top of workpiece. Zero knee micrometer dial.	___	___	___	___
9. Back cutter up and away from workpiece. Start spindle. Set for first pass and engage longitudinal feed. Complete cut. Check workpiece with radius gage.	___	___	___	___

10. Continue raising knee, moving transverse hand crank and taking successive passes until dials are zeroed. Check with radius gage to prevent undercutting dimension. Radius should now be at full depth. _ _ _ _

11. Remove workpiece and deburr. Remove cutting tool and return all tools to storage. _ _ _ _

Average of above evaluations* _ _ _ _

*This average is the student's final evaluation for competency J15: Form mill workpiece.

MODULE: MILLING

UNIT VIII: FORM MILLING

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. Which of the operations listed below is not considered a form milling operation?

a. Boring
b. Radius
c. Chamfer
d. Concave
e. None of the above

____ 2. One method for ensuring proper blending of surfaces in form milling uses which of the following tools?

a. A dial gage
b. Layout dye
c. Steel rule
d. Vernier caliper
e. None of the above

____ 3. Which of the following is true with respect to form milling as compared to standard end mill operation?

a. Speeds and feeds are the same.
b. Speeds and feeds are slower.
c. Speeds and feeds are higher.
d. Speeds are higher, but feeds are lower.
e. Speeds are lower, but feeds are higher.

____ 4. Which tool would be employed to measure concave forms?

a. Steel rule
b. Vernier caliper
c. Micrometer caliper
d. Radius gage
e. Pocket rule

ANSWERS TO UNIT TEST (J15)

1. a
2. b
3. b
4. d

MODULE: MILLING

UNIT IX: MACHINING KEYWAYS

UNIT OBJECTIVE

In this unit the student will learn to machine square external keyways and Woodruff keyways on workpieces mounted in V-blocks on a vertical milling machine table. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

Upon completion of the lessons in this unit, the student should be able to:

1.1 Identify keyway types and formulas used to calculate cut depths.

1.2 Mill a plain keyway. (competency J16 and J17, JS 1.1)

2.1 Identify terms and definitions related to Woodruff keyways.

2.2 Describe cutter and key size specifications.

2.3 Select appropriate keys for different sized shafts.

2.4 Machine a Woodruff keyway. (competency J18, JS 2.1)

MODULE: MILLING

UNIT IX: MACHINING KEYWAYS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: PLAIN KEYWAY MILLING
    a. Information outline
    b. Assignment sheet
        AS 1.1: Keyway calculations
    c. Job sheet
        JS 1.1: Mill a plain keyway
2. Lesson 2: MILLING WOODRUFF KEYWAYS
    a. Information outline
    b. Job sheet
        JS 2.1: Machine a Woodruff keyway

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.
2. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guides/materials

1. Apprentice Machinist (AFSC 53130). Vol. I. Machine Shop Fundamentals. Gunter Air Force Base, AL: Extension Course Institute, Air University, 1981.

2. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

3. Benson, Robert T., and Margaret R. Gregory. V-TECS Guide for Machine Shop. Columbia, SC: South Carolina Department of Education, 1985.

4. Dunn, James. Machine Shop I. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1981.

5. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

6. Grimes, L. Machinist. Austin: Center for Occupational Curriculum Development, University of Texas at Austin, 1982.

7. Yettaw, Jerome. Vocational Machine Shop. University of Missouri-Columbia: Instructional Materials Laboratory, 1977.

C. Other references

1. "1983 Mechanical Drives Reference Issue." Machine Design 30 June 1983.

2. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

NOTES TO THE INSTRUCTOR

A. Suggested supplemental materials

1. Oberg, Erik; Franklin D. Jones; Holbrook L. Horton. Machinery's Handbook. New York: Industrial Press Inc. 22nd ed., 1984; 23rd ed., 1988.

MODULE: MILLING

UNIT IX: MACHINING KEYWAYS

LESSON 1: PLAIN KEYWAY MILLING

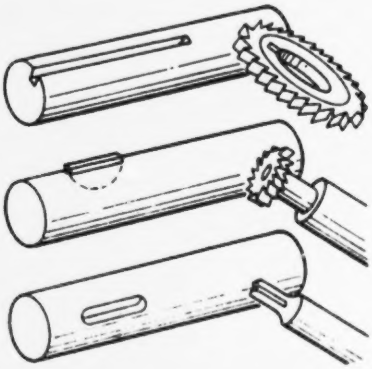
I. Keyway--essentially a groove cut into a shaft

A. Types of keyways

1. Plain keyways can be cut with an end mill in a vertical milling machine or with a plain milling cutter in a horizontal milling cutter.

2. Woodruff keyways are cut by a Woodruff keyway cutter.

3. Closed keyways are cut with an end mill.



Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 292.

B. Calculating depth of keyway cut

1. There is some error in engineering drawings of keyways. Dimensioning generally does not take into consideration that the workpiece is round.

2. To cut to full depth, the workpiece must be raised into the cutter the depth of the keyway plus the height of the arc. This arc varies depending upon the radius of the workpiece and the width of the keyway.

3. Calculate height of arc.

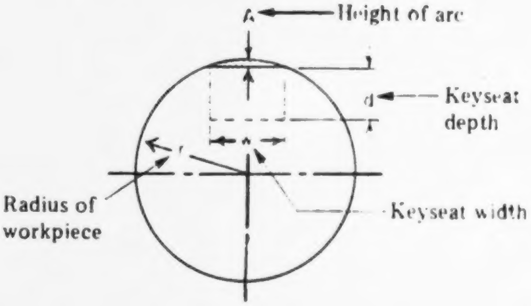
$$A = r - \sqrt{r^2 - (1/2w)^2}$$

A = height of arc
r = radius of work
w = keyway width

4. Calculate total depth of cut.

Total depth = 1/2(w) + A

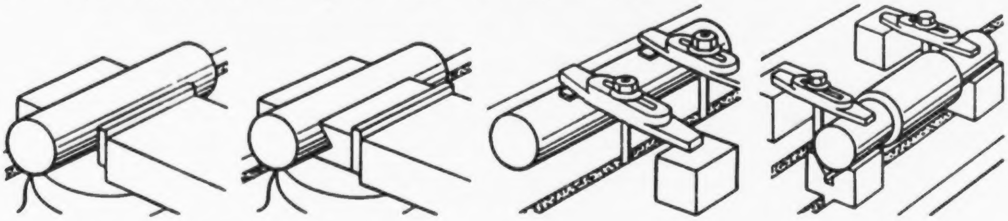
w = keyway width
A = arc height



Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 293.

EXAMPLE: Calculate the total depth of cut to mill a 5/16" square keyway on a 2" diameter shaft.

C. Four methods of holding round work are shown below.



Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 293.

II. Procedure for cutting a plain keyway

A. Mount and secure workpiece.

B. Select a high-speed steel end mill.

NOTE: The diameter of the end mill must be small enough to produce the desired key width.

C. Align workpiece so that it is centered with the cutter.

D. Set spindle speed.

E. Set table feed.

F. Start spindle. Raise knee until cutter grazes top of shaft. Set knee micrometer dial at zero.

G. Move cutter to starting position away from workpiece. Raise knee to obtain calculated depth of cut.

H. Feed cutter by hand a short distance. Back out and check depth with steel rule. Width can be checked with a piece of key stock.

I. Make necessary adjustments. Lock knee. Engage power feed and finish cut.

J. Brush away chips and remove burrs.

KEYWAY CALCULATIONS

Given the following formula, calculate the arc for the following plain keyway milling operations. Show all work.

$$A = r - \sqrt{r^2 - (1/2w)^2}$$

A = height of arc
r = radius of work
w = keyway width

1. 1/8" square key; 1/2" diameter shaft

2. 1/4" square key, 1" diameter shaft

3. 3/4" square key, 3" diameter shaft

Using the following formula, calculate the total depth of cut for the milling operations above. Show all work.

$$\text{Total depth} = 1/2(w) + A$$

w = keyway width
A = arc height

4. 1/8" square key; 1/2" diameter shaft

5. 1/4" square key, 1" diameter shaft

6. 3/4" square key, 3" diameter shaft

ANSWERS TO AS 1.1

1. (1/8 key, 1/2" dia.) $r = .250, w = .125$

$A = .250 - \sqrt{(.250)^2 - [(1/2)(.125)]^2}$

$A = .250 - \sqrt{.0625 - .0039062}$

$A = .250 - \sqrt{.0585938}$

$A = .250 - .2420615$

$A = .0079$

2. (1/4 sq. key, 1" dia.) $r = .50, w = .250$

$A = .50 - \sqrt{(.50)^2 - [(1/2)(.250)]^2}$

$A = .50 - \sqrt{0.25 - 0.015625}$

$A = .50 - \sqrt{0.234375}$

$A = .50 - .4841229$

$A = 0.0158771$ or 0.016

3. (3/4 sq. key, 3" dia.) $r = 1.50, w = .375$

$A = 1.50 - \sqrt{(1.50)^2 - [(1/2)(.375)]^2}$

$A = 1.50 - \sqrt{2.25 - 0.0351562}$

$A = 1.50 - \sqrt{2.2148438}$

$A = 1.50 - 1.4882351$

$A = 0.0117649$ or 0.012

4. $(.5)(.125) + .0079 = 0.0704$

5. $(.5)(.250) + 0.016 = .141$

6. $(.5)(.750) + 0.012 = 0.387$

JS 1.1

MILL A PLAIN KEYWAY

Equipment:

1/4" end mill
Length of 1" cold rolled bar stock (about 6" in length)
Steel rule
1/4" key stock
0-1" micrometer
Matching V-block set
Strap clamp set

NOTE: Before proceeding, calculate full depth of cut required. The keyway will be .250" wide x .125" deep on a 1" shaft diameter.

Height of arc:

$$A = r - \sqrt{r^2 - (1/2w)^2}$$

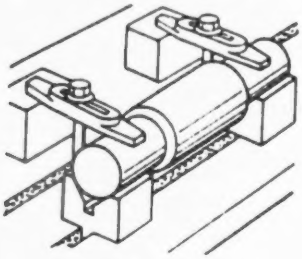
A = height of arc
r = radius of work
w = keyway width

Full depth of cut formula:

Total depth = 1/2(w) + A

w = keyway width
A = arc height

Procedure:	Evaluation 3	2	1	N
1. Mount and secure workpiece using V-blocks and strap clamps as shown below.	__	__	__	__



Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 293.

Procedure:	3	2	1	N
2. Select a 1/4" high-speed steel end mill. Check diameter of cutter with micrometer.	__	__	__	__
3. Align workpiece so that it is centered with the cutter.	__	__	__	__
4. Set spindle speed. Set table feed. Start spindle. Raise knee until cutter grazes top of shaft. Set knee micrometer dial at zero.	__	__	__	__
5. Move cutter to starting position away from workpiece. Raise knee to obtain calculated depth of cut.	__	__	__	__
6. Feed cutter by hand a short distance. Back out and check depth with steel rule. Width can be checked with a piece of key stock.	__	__	__	__
7. Make necessary adjustments. Lock knee. Apply cutting fluid and engage power feed and finish cut.	__	__	__	__

8. Brush away chips and remove burrs.				
9. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.				
Average of above evaluations*				

*This average is the student's final evaluation for competencies J16 and J17.

MODULE: MILLING

UNIT IX: MACHINING KEYWAYS

LESSON 2: MILLING WOODRUFF KEYWAYS

I. Terms and definitions

   A. Woodruff key--specially shaped key which provide positive drive between a shaft and hub. Because of its shape, a Woodruff key cannot slide out of position while a mechanism is in operation.

   B. Woodruff key number--identification number by which the size of a key or cutter can be designated.

   C. Woodruff keyway--a circular pocket machined in a shaft in which the Woodruff key is held.

   D. Woodruff keyway cutter--a milling cutter used for machining Woodruff keys

II. Cutter and key size specifications

   A. Cutters and keys come in standard sizes.

   B. The number designates size.

      1. The last two digits indicate cutter diameter in eighths of an inch.

      2. One or two digits preceding the last two digits indicate cutter width in 32nds of an inch.

      EXAMPLES:

      506 Woodruff key or cutter
      ↗ ↖↖
      5/32" (6/8" or)
      wide x 3/4" diameter

      202 Woodruff key or cutter
      ↗ ↖↖
      (2/32") (2/8")
      1/16"
      wide x 1/4" diameter

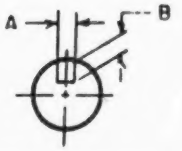
III. Key above shaft height

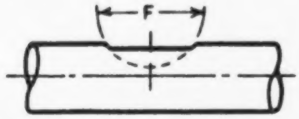
   A. Specifications for this important dimension are given using different keys for different shaft diameters.

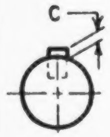
   B. Generally, the key should project above the shaft a distance equal to one-half the cutter width.

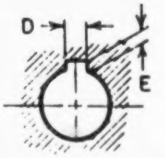
   C. Depth tolerance is +0.005/-0.000.

   D. An important dimension in the table that follows is "Depth B", which is the depth the cutter is fed into the shaft for the various keys shown. A more complete table can be found in the Machinery's Handbook or is available from cutter manufacturers.









Woodruff		Keyseat Shaft					Key above Shaft	Keyseat Hub	
		Width A*†		Depth B†	Diameter F		Height C†	Width D†	Depth E
Key Number	Nominal Size Key	Min.	Max.	+0.005 -0.000	Min.	Max.	+0.005 -0.005	+0.002 -0.000	+0.005 -0.000
202	1/16 X 1/4	0.0615	0.0630	0.0728	0.250	0.268	0.0312	0.0635	0.0372
202.5	1/16 X 5/16	0.0615	0.0630	0.1038	0.312	0.330	0.0312	0.0635	0.0372
302.5	3/32 X 5/16	0.0928	0.0943	0.0882	0.312	0.330	0.0469	0.0948	0.0529
				. . .					
406	1/8 X 3/4	0.1240	0.1255	0.2455	0.750	0.768	0.0625	0.1260	0.0685
506	5/32 X 3/4	0.1553	0.1568	0.2299	0.750	0.768	0.0781	0.1573	0.0841
606	3/16 X 3/4	0.1863	0.1880	0.2143	0.750	0.768	0.0937	0.1885	0.0997
806	1/4 X 3/4	0.2487	0.2505	0.1830	0.750	0.768	0.1250	0.2510	0.1310
				. . .					
1228	3/8 X 3-1/2	0.3735	0.3755	0.7455	3.500	3.535	0.1875	0.3760	0.1935
1428	7/16 X 3-1/2	0.4360	0.4380	0.7143	3.500	3.535	0.2187	0.4385	0.2247
1628	1/2 X 3-1/2	0.4985	0.5005	0.6830	3.500	3.535	0.2500	0.5010	0.2560
1828	9/16 X 3-1/2	0.5610	0.5630	0.6518	3.500	3.535	0.2812	0.5635	0.2872
2028	5/8 X 3-1/2	0.6235	0.6255	0.6205	3.500	3.535	0.3125	0.6260	0.3185
2228	11/16 X 3-1/2	0.6860	0.6880	0.5893	3.500	3.535	0.3437	0.6885	0.3497
2428	3/4 X 3-1/2	0.7485	0.7505	0.5580	3.500	3.535	0.3750	0.7510	0.3810

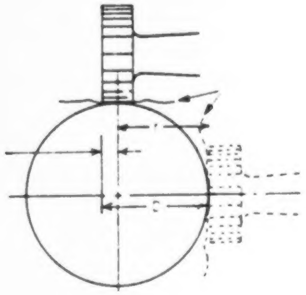
***Values for width A represent the *maximum* keyseat (shaft) width that will assure the key will stick in the keyseat (shaft). The *minimum* keyseat width permits the largest shaft distortion acceptable when assembling a maximum key in a minimum keyseat.**

†Dimensions A, B, C, and D are taken at the side intersection.

Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 295 and 296.

IV. Procedure for machining a Woodruff keyway

A. Aligning the cutter and workpiece



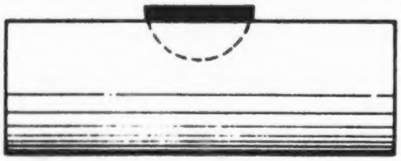
1. Center cutter over workpiece. Raise knee carefully to bring workpiece into contact with cutter. Use tissue paper to determine when contact is made. Zero the knee micrometer dial.

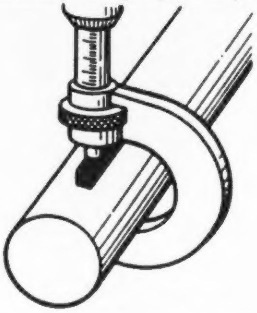
2. Clear the cutter from the workpiece. Raise the knee a distance equal to the radius of the workpiece plus one-half the width of the cutter.

B. Machining the keyway

1. Start spindle. Carefully move the transverse axis until the cutter grazes the outside diameter of the workpiece.

2. Apply a steady flow of coolant and advance the cutter into the workpiece the required depth. (See tables like the previous one for this data.)
3. If machined properly, the key should require a light tap with a rubber-faced mallet to be seated.
4. Measure total height of workpiece and key to check that proper depth of cut was achieved.





Credit: Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982, pg. 296.

JS 2.1

MACHINE A WOODRUFF KEYWAY

Equipment:

406, 506 or 606 Woodruff keyway cutter with corresponding Woodruff key
0-1" micrometer
1-2" micrometer
Tissue paper feeler
Milling vise
Dial indicator
Machinery's Handbook
Rubber-faced hammer
Workpiece (8-10" length of 1" diameter cold-rolled steel)

Procedure:	Evaluation			
	3	2	1	N
1. Mount vise on milling table and align with dial indicator.	___	___	___	___
2. Mount workpiece securely in vise. Portion to be machined should extend out from the vise jaws.	___	___	___	___
3. Select cutter. Verify diameter and width with micrometer. Mount cutter in spindle using R-8 collet.	___	___	___	___
4. Set spindle speed.	___	___	___	___
5. Align cutter with workpiece.	___	___	___	___
a. Raise knee carefully to bring workpiece into contact with cutter. Use tissue paper to determine when contact is made. Zero the knee micrometer dial.				
b. Clear the cutter from the workpiece. Raise the knee a distance equal to the workpiece's radius plus one-half the width of the cutter. Engage longitudinal axis and knee locking mechanisms.				
6. Start spindle. Carefully move the transverse axis until the cutter grazes the outside diameter of the workpiece.				
7. Apply a steady flow of coolant and advance the cutter into the workpiece the required depth (see tables for this data).	___	___	___	___
8. Deburr as needed. Install key. If seat is properly machined, key should require a light tap with a rubber-faced mallet to be seated.	___	___	___	___
9. Measure total height of workpiece and key to check that proper depth of cut was achieved.	___	___	___	___
10. Clean machine and work area. Return all tools to storage.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is the student's final evaluation for competency J18: Machine Woodruff keyway.

MODULE: MILLING

UNIT IX: MACHINING KEYWAYS

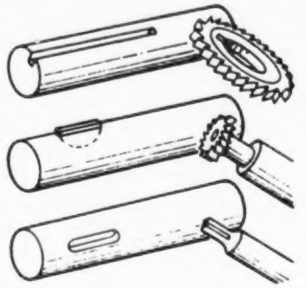
UNIT TEST

Match the type of keyway shown below with appropriate names.

____ 1.

____ 2.

____ 3.



a. Woodruff
b. Plain
c. Gib
d. Closed
e. Open

Select the option which answers the question or completes the statement.

____ 4. Why is it necessary to calculate the depth of cut for a plain keyway even when an engineering drawing of the part feature is available?

a. The drawing may not have been made properly.
b. Machine tolerances can vary.
c. The overall dimension of the key can change as it is machined.
d. The drawing dimension does not reflect the height of the arc required.
e. No such calculation is necessary.

____ 5. Which of the following is true with respect to the cutter selected for machining a plain keyway?

a. Its diameter must be small enough to produce the desired keyway width.
b. It must not have more than two flutes.
c. It must be run at twice the recommended rpm to maintain good surface finish.
d. It must not be used more than once because of excessive wear caused by high-speed machining.
e. None of the above

____ 6. What dimensions would an 806 Woodruff keyway cutter have?

a. 5/32" x 3/4"
b. 1/8" x 3/4"
c. 4/8" x 8/32"
d. 1/2" x 3/4"
e. 1/4" x 3/4"

____ 7. How is the proper depth of cut for a Woodruff keyway best determined?

a. Ask the instructor
b. Estimate
c. Calculate using arc height formula
d. Refer to tables
e. None of the above

____ 8. How is depth tolerance for a Woodruff keyway specified?

a. +0.0005/-0.0000
b. +0.005/-0.000
c. +0.000/-0.005
d. ±0.005
e. None of the above

____ 9. How is workpiece and Woodruff keyway cutter alignment accomplished?

a. Move the longitudinal feed one-half the cutter diameter plus the workpiece diameter.
b. Lower the quill one-half the workpiece diameter.
c. Raise the knee two times the cutter diameter.
d. Move the transverse feed to full depth of cut.
e. Raise the knee a distance equal to one-half the workpiece diameter plus one-half the width of the cutter.

____ 10. Which of the following is not a recommended method for holding a round workpiece on a milling machine for keyway operations?

a. Clamp the workpiece directly to the table.
b. Mount workpiece vertically in vise.
c. Mount workpiece in vise with V-blocks.
d. Clamp workpiece to table using V-blocks.
e. Mount workpiece directly in milling vise.

____ 11. Which of the following is a circular pocket machined in a shaft?

a. Woodruff key
b. Woodruff key number
c. Woodruff keyway
d. Woodruff keyway cutter
e. Plain keyway

ANSWERS TO UNIT TEST

1. b (E17, E18)
2. a (E17, E18)
3. d (E17, E18)
4. d (E17)
5. a (E17)
6. e (E18)
7. d (E18)
8. b (E18)
9. e (E18)
10. b (E16)
11. c (E18)

MODULE: MILLING

UNIT X: MILLING ANGULAR SURFACES

UNIT OBJECTIVE

In this unit, the student will practice three methods for setting up and milling an angular surface. This knowledge will be evidenced by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

Upon completion of the lessons in this unit, the student should be able to:

1.1 Mill an angular surface by tilting the milling head. (partial J19, JS 1.1)

2.1 Mill an angular surface on a workpiece using an angle vise or fixture. (partial J19, JS 2.1)

3.1 Mill an angular surface on a workpiece with a standard milling vise. (J19, JS 3.1)

MODULE: MILLING

UNIT X: MILLING ANGULAR SURFACES

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

  1. Lesson 1: TILTING THE HEAD

    a. Information outline

    b. Job sheet

      JS 1.1: Mill an angular surface by tilting the milling head

  2. Lesson 2: USING AN ANGLE VISE OR PLATE

    a. Information outline

    b. Job sheet

      JS 2.1: Mill an angular surface with an angle vise

  3. Lesson 3: STANDARD MILLING VISE

    a. Information outline

    b. Job sheet

      JS 3.1: Mill an angular surface with a standard milling vise

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

2. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

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1. Apprentice Machinist (AFSC 53130). Vol. I. Machine Shop Fundamentals. Gunter Air Force Base, AL: Extension Course Institute, Air University, 1981.
2. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.
3. Benson, Robert T., and Margaret R. Gregory. V-TECS Guide for Machine Shop. Columbia, SC: South Carolina Department of Education, 1985.
4. Dunn, James. Machine Shop I. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1981.
5. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.
6. Grimes, L. Machinist. Austin: Center for Occupational Curriculum Development, University of Texas at Austin, 1982.
7. Yettaw, Jerome. Vocational Machine Shop. University of Missouri-Columbia: Instructional Materials Laboratory, 1977.

C. Other references

1. "1983 Mechanical Drives Reference Issue." Machine Design 30 June 1983.
2. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

MODULE: MILLING

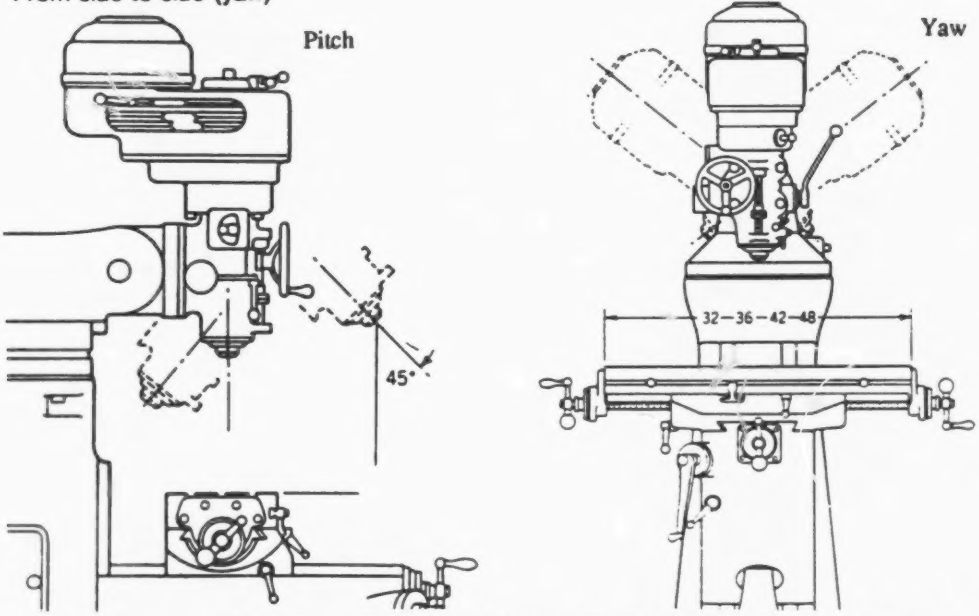
UNIT X: MILLING ANGULAR SURFACES

LESSON 1: TILTING THE HEAD

I. The head on a vertical milling machine can be tilted.

  A. From front to back (pitch)

  B. From side to side (yaw)



Credit: "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d., pg. 1.

  C. Procedure for milling an angle by tilting the head

    1. Determine which axis is to be tilted (pitch or yaw).

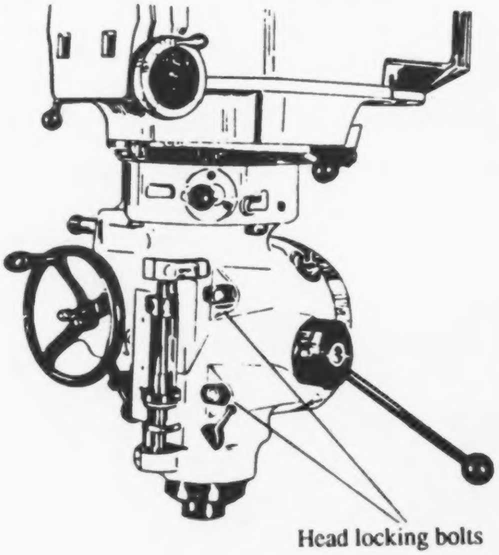
    2. Loosen bolts on milling head.

    3. Tilt head by turning adjustment bolt. Use graduations on side of milling head to determine proper angle.

    4. Take test cut on scrap material. Measure angle with protractor or set up on surface plate using gage blocks, sine bar or dial indicator.

    5. Mount workpiece and perform operation.

Credit: Bridgeport Machines, Inc.



JS 1.1

MILL AN ANGULAR SURFACE BY TILTING THE MILLING HEAD

Equipment:

1/2" or larger end mill
Combination set protractor
Tool set for milling machine (wrenches, etc.)
Milling vise
Bench rule
Workpiece provided by instructor
Dial indicator

		Evaluation			
Procedure:		3	2	1	N
1.	Align vise with table. Mount workpiece in vise.	___	___	___	___
2.	Loosen bolts on front of milling head.	___	___	___	___
3.	Tilt top to the left by turning adjustment bolt. Use graduations on side of milling head to determine proper angle. Turn until graduations read 45°.	___	___	___	___
4.	Take shallow test cut on workpiece. Measure angle with protractor. Tolerance of angle is ± 1°. If angle is not correct, adjust head as needed.	___	___	___	___
5.	Tighten head bolts. Set depth and complete cut. Check proper width of angle with bench rule.	___	___	___	___
6.	As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.	___	___	___	___
Average of above evaluations*		___	___	___	___

*This average is one-third of the student's final evaluation for competency J19: Mill angular surfaces.

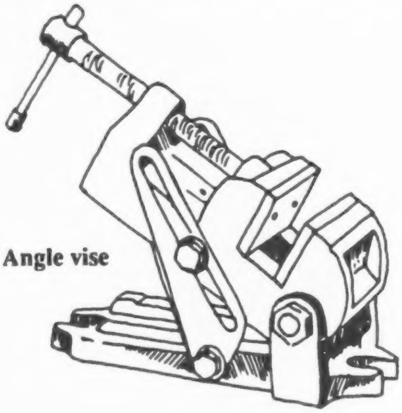
MODULE: MILLING

UNIT X: MILLING ANGULAR SURFACES

LESSON 2: USING AN ANGLE VISE OR SINE PLATE

I. Fixtures for angle milling

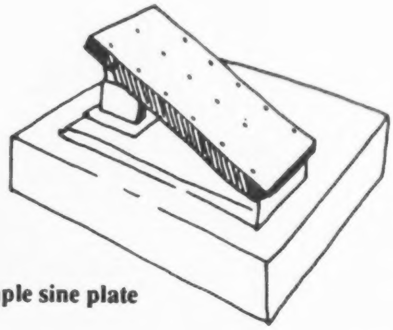
A. Angle vise--holds workpiece as a standard vise and then tilts to the desired angle.



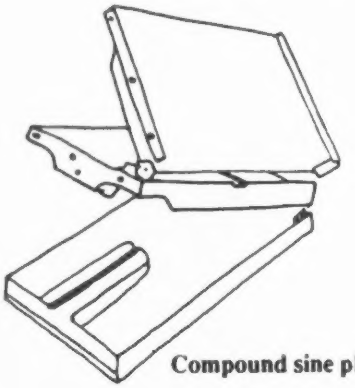
Angle vise

B. Sine plate--workpiece is clamped to plate; plate is tilted to proper angle using gage blocks

NOTE: Review section on sine bars from Precision Measurement if necessary.



Simple sine plate



Compound sine plate

C. Procedure for angle milling using an angle vise

1. Align vise with table. Mount workpiece.
2. Set angle vise to desired angle.
3. Take a shallow test cut on the workpiece. Check angle. Adjust vise angle as necessary.
4. Complete procedure as per drawing.

JS 2.1

MILL AN ANGULAR SURFACE WITH AN ANGLE VISE

Equipment:

Angle vise
1/2" or larger end mill
Combination set protractor
Bench rule
Workpiece provided by instructor
Dial indicator

	Evaluation			
Procedure:	3	2	1	N
1. Align vise with table. Mount workpiece.	___	___	___	___
2. Set angle vise at 25°.	___	___	___	___
3. Install end mill. Set spindle speed. Adjust for shallow cut.	___	___	___	___
4. Check angle with protractor. Adjust angle as needed. Tolerance is ± 1°.	___	___	___	___
5. Complete cut. Check angle and other measurements as per drawing.	___	___	___	___
6. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.	___	___	___	___
Average of above evaluations*	___	___	___	___

*This average is one-third of the student's final evaluation for competency J19: Mill angular surfaces.

MODULE: MILLING

UNIT X: MILLING ANGULAR SURFACES

LESSON 3: STANDARD MILLING VISE

I. Angle milling can be accomplished in a standard vise.

   A. Tolerance must be ± 3° or greater.

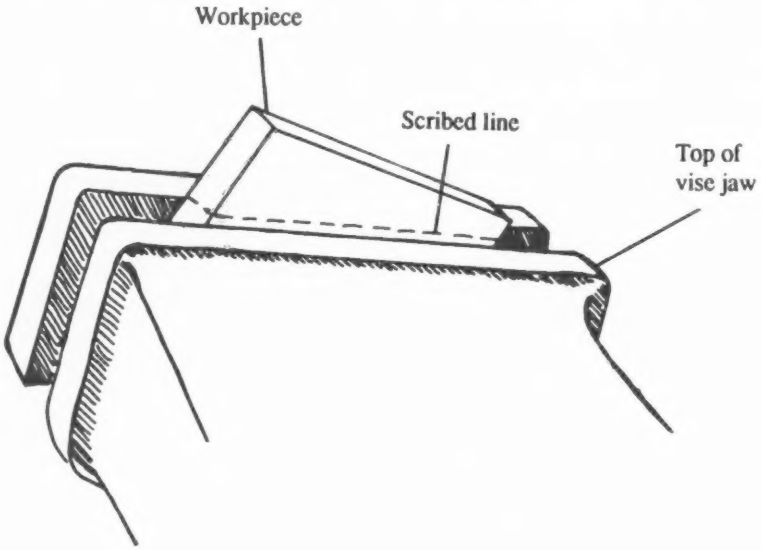
   B. Procedure

      1. Scribe lines on workpiece to indicate angle cutting line.

      2. Mount and align milling vise.

      3. Mount workpiece in vise by carefully aligning scribe line even with top of vise jaw. Line should be parallel and slightly above top of vise jaw.

      4. Mill to the line. Check angle with protractor.



JS 3.1

MILL AN ANGULAR SURFACE WITH A STANDARD MILLING VISE

Equipment:

Surface plate
Sine plate and gage blocks
Surface gage
Layout dye
1/2" or larger end mill
Combination set protractor
Milling vise
Bench rule
Workpiece provided by instructor
Dial indicator

	Evaluation			
Procedure:	3	2	1	N
1. Scribe a line on workpiece to indicate angle cutting line using surface plate, sine plate and gage blocks, and surface gage.				
2. Mount and align milling vise.				
3. Mount workpiece in vise by carefully aligning scribe line even with top of vise jaw. Line should be parallel and slightly above top of vise jaw.				
4. Mill to the line. Check angle with protractor or on sine plate with dial indicator. Tolerance on angle is ± 3°.				
5. Clean up area, returning tools and materials.				
Average of above evaluations*				

*This average completes the student's final evaluation for competency J19: Mill angular surfaces.

MODULE: MILLING

UNIT X: MILLING ANGULAR SURFACES

UNIT TEST

Select the option which best answers the question or completes the statement.

____ 1. What is side-to-side milling head movement referred to as?

- a. X-axis
- b. Yaw
- c. Pitch
- d. Rotary
- e. None of the above

____ 2. What instrument is used for initial measurement of angular adjustment of the milling head?

- a. Bench rule
- b. Protractor
- c. Milling head angle graduations
- d. Dial gage
- e. None of the above

____ 3. Which of the following is a fixture which can used for milling angles?

- a. Sine plate
- b. Strap clamp
- c. Dial gage
- d. Protractor
- e. None of the above

____ 4. Why is it advisable to take a test cut on the workpiece before setting for a final cut?

- a. To verify proper speeds and feeds
- b. To properly adjust coolant flow
- c. To verify depth of cut
- d. To verify angle setting
- e. None of the above

____ 5. Which of the following would not be used to test an angle after milling?

- a. Bench rule
- b. Protractor
- c. Sine bar and gage blocks
- d. Dial gage
- e. Surface plate

ANSWERS TO UNIT TEST (J19)

1. b
2. c
3. a
4. d
5. a

MODULE: MILLING

UNIT XI: ROTARY TABLES AND INDEXING

UNIT OBJECTIVE

In this unit the student will learn to use a rotary table to machine a radial slot (internal and external radii) on a workpiece. In addition, the student will use a dividing head to machine a hexagon on a round workpiece. This knowledge will be demonstrated by achieving a specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

Upon completion of the lessons in this unit, the student should be able to:

1.1 Mill external and internal radii with a rotary table. (competency J20 and J21, JS 1.1)

2.1 Describe indexing head uses and components.

2.2 Describe direct indexing uses and limitations.

2.3 Mill workpiece using an indexing head. (competency J22, JS 2.1)

MODULE: MILLING

UNIT XI: ROTARY TABLES AND INDEXING

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

1. Lesson 1: MILLING INTERNAL AND EXTERNAL RADII
   - a. Information outline
   - b. Job sheet
     - JS 1.1: Mill external and internal radii with rotary table
2. Lesson 2: SIMPLE INDEXING OPERATIONS
   - a. Information outline
   - b. Assignment sheet
     - AS 2.1: Indexing calculations
   - c. Job sheet
     - JS 2.1: Mill workpiece using an indexing head

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

2. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

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1. Apprentice Machinist (AFSC 53130). Vol. I. Machine Shop Fundamentals. Gunter Air Force Base, AL: Extension Course Institute, Air University, 1981.

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7. Yettaw, Jerome. Vocational Machine Shop. University of Missouri-Columbia: Instructional Materials Laboratory, 1977.

C. Other references

1. "1983 Mechanical Drives Reference Issue." Machine Design 30 June 1983.

2. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

MODULE: MILLING

UNIT XI: ROTARY TABLES AND INDEXING

LESSON 1: MILLING INTERNAL AND EXTERNAL RADII

I. Rotary table uses and make-up

  A. Uses

    1. Milling curve slots and other curved features

    2. Spacing holes at given angles apart

  B. Parts of the rotary table

    1. Base

    2. Hand crank

    3. Angle graduations

      a. 1/2° (30 minute) graduations

      b. Addition of vernier plate gives direct readings to within 5 seconds of arc.

    4. Table with T-slots for clamping

    5. Angle block for vertical mounting

    6. Tailstock for holding long workpiece in horizontal position

II. Procedure for milling radial slot with rotary table

  A. Mount rotary table to milling table. Align spindle with center of table.

  B. Mount workpiece to rotary table. Align workpiece with dial indicator.

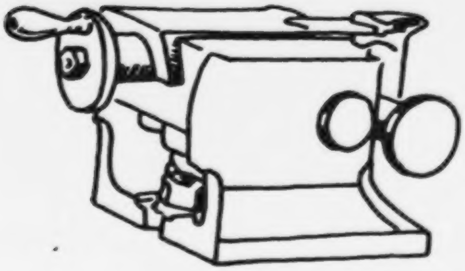
  C. Mount end mill in spindle. Select appropriate spindle speed.

  D. Turn transverse hand crank until center of spindle is over center location of slot to be milled.

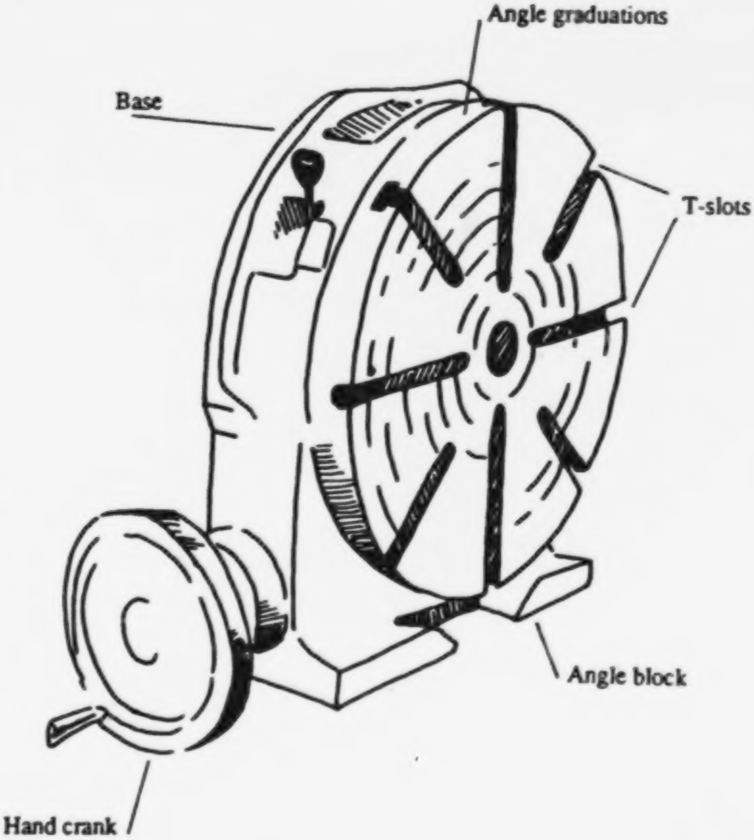
  E. Raise knee until end mill grazes top of workpiece. Apply coolant. Set desired depth of cut.

  F. Turn rotary table hand crank until end mill has traveled 360° and slot is complete.

  G. Check workpiece with vernier caliper.



TAILSTOCK


Angle graduations
Base
T-slots
Angle block
Hand crank

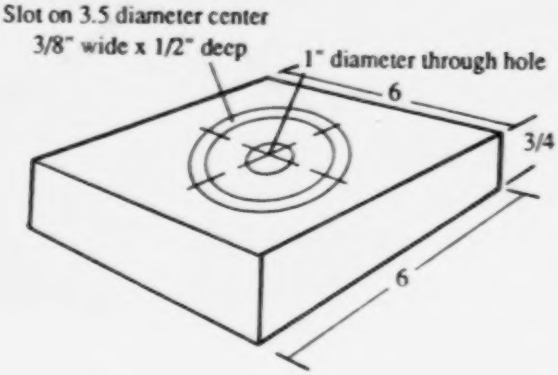
ROTARY TABLE

JS 1.1

MILL EXTERNAL AND INTERNAL RADII WITH ROTARY TABLE

Equipment:

Workpiece provided by instructor
Rotary table
Clamping set with T-bolts
Dial test indicator
Vernier calipers
3/8" end mill (must be center-cutting type)



Procedure:		Evaluation 3	2	1	N
1.	Mount rotary table to milling table. Using dial indicator, align spindle with center of table.	__	__	__	__
2.	Mount workpiece to rotary table. Align workpiece with dial indicator using center hole in workpiece as a reference.	__	__	__	__
3.	Mount end mill in spindle. Select appropriate spindle speed.	__	__	__	__
4.	Turn transverse hand crank until center of spindle is over center location of slot to be milled.	__	__	__	__
5.	Raise knee until end mill grazes top of workpiece. Apply coolant. Set desired depth of cut by feeding end mill into workpiece.	__	__	__	__
6.	Turn rotary table hand crank until end mill has traveled 360° and slot is complete.	__	__	__	__
7.	Check workpiece with vernier caliper.	__	__	__	__
8.	As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.	__	__	__	__
Average of above evaluations*		__	__	__	__

*This average is the student's final evaluation for competencies J20 and J21.

MODULE: MILLING

UNIT XI: ROTARY TABLES AND INDEXING

LESSON 2: SIMPLE INDEXING OPERATIONS

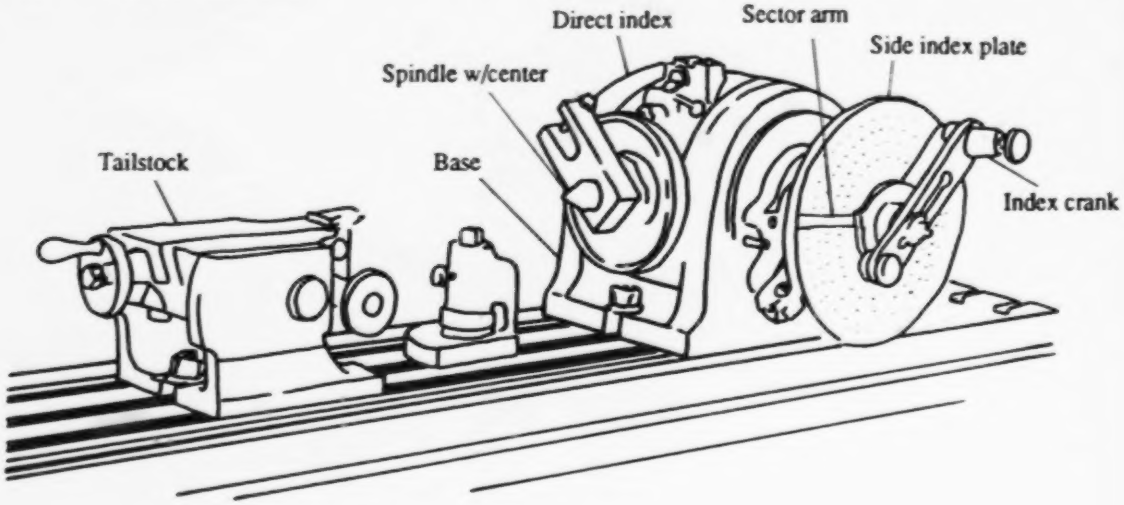
I. Dividing head (also known as indexing head)

  A. Uses

    1. Holding workpiece between centers

    2. Machining features at precise angles or distances apart (e.g. gear teeth, holes, splines, etc.)

  B. Major components


Direct index
Sector arm
Side index plate
Spindle w/center
Tailstock
Base
Index crank

II. Direct indexing

  A. Simplest method

  B. Makes use of direct indexing plate

  C. 1:1 ratio of movement of crank to spindle

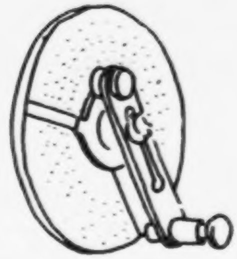
  D. Has 24 equally spaced holes and plunger pin for positioning

  E. Can be used to divide a circle into 24, 12, 8, 6, 4, 3 or 2 equal parts

III. Simple indexing

  A. Allows indexing of divisions beyond those attainable by direct indexing

  B. Makes use of side indexing plates and worm reducing gear



1. Worm gearing provides a 40:1 ratio between the turning of the crank and the spindle rotation.

2. The indexing plate is reversible and has 22 concentric circles of holes drilled in it--11 on each side. Circles of holes in reversible index plate are shown below.

    a. Side one:
    24/25/28/30/34/37/38/39/41/42/43

    b. Side two:
    46/47/49/51/53/54/57/58/59/62/66

3. The table below shows number of divisions, circle to use and number of turns required.

No. of Divisions	Circle	Turns	Holes	No. of Divisions	Circle	Turns	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes
2	any	20	....	23	46	1	34	44	66	60	68	34	20	104	39	15	150	30	8	205	41	8	280	28	4
3	24	13	8	24	24	1	16	45	54	48	70	28	16	105	42	16	152	38	10	210	42	8	290	58	8
4	any	10	....	25	25	1	15	46	46	40	72	54	30	106	53	20	155	62	16	212	53	10	296	37	5
5	any	8	....	26	39	1	21	47	47	40	74	37	20	108	54	20	156	39	10	215	43	8	300	30	4
6	24	6	16	27	54	1	26	48	24	20	75	30	16	110	66	24	160	28	7	216	54	10	304	38	5
7	28	5	20	28	42	1	18	49	49	40	76	38	20	112	28	10	164	41	10	220	66	12	310	62	8
8	any	5	....	29	58	1	22	50	25	20	78	39	20	114	57	20	165	66	16	224	28	5	312	39	5
9	54	4	24	30	24	1	8	51	51	40	80	34	17	115	46	16	168	42	10	228	57	10	320	24	3
10	any	4	....	31	62	1	18	52	39	30	82	41	20	116	58	20	170	34	8	230	46	8	328	41	5
11	66	3	42	32	28	1	7	53	53	40	84	42	20	118	59	20	172	43	10	232	58	10	330	66	8
12	24	3	8	33	66	1	14	54	54	40	85	34	16	120	66	22	176	66	15	235	47	8	336	42	5
13	39	3	3	34	34	1	6	55	66	48	86	43	20	124	62	20	180	54	12	236	59	10	340	34	4
14	49	2	42	35	28	1	4	56	28	20	88	66	30	125	25	8	184	46	10	240	66	11	344	43	5
15	24	2	16	36	54	1	6	57	57	40	90	54	24	130	39	12	185	37	8	245	49	8	360	54	6
16	24	2	12	37	37	1	3	58	58	40	92	46	20	132	66	20	188	47	10	248	62	10	368	46	5
17	34	2	12	38	38	1	2	59	59	40	94	47	20	135	54	16	190	38	8	250	25	4	370	37	4
18	54	2	12	39	39	1	1	60	42	28	95	38	16	136	34	10	192	24	5	255	51	8	376	47	5
19	38	2	4	40	any	1	....	62	62	40	96	24	10	140	28	8	195	39	8	260	39	6	380	38	4
20	any	2	....	41	41	....	40	64	24	15	98	49	20	144	54	15	196	49	10	264	66	10	390	39	4
21	42	1	38	42	42	....	40	65	39	24	100	25	10	145	58	16	200	30	6	270	54	8	392	49	5
22	66	1	54	43	43	....	40	66	66	40	102	51	20	148	37	10	204	51	10	272	34	5	400	30	3

Credit: Cincinnati Milacron

4. Machinists can also use the following formula to determine number of revolutions.

    T = 40 ÷ N

    T = number of turns of crank

    40 = worm gear ratio

    N = number of divisions wanted

5. Angular indexing can also be achieved.

    a. Each full index crank revolution turns the 9° or workpiece one-quarter of a turn.

    b. The number of index cranks is calculated as:

    Number of turns (T) = angle ÷ 9

C. Sector arms

1. Adjustable

2. Permit setting of fractional portions of a turn

D. The tailstock permits holding of long workpieces.

INDEXING CALCULATIONS

Determine the answers to the following questions, showing all work below the question and writing the answer on the space provided.

____ 1. What is the number of turns required to machine a reamer having 9 flutes?

____ 2. How many turns are required to machine a 40-tooth gear?

____ 3. How many turns are required to drill two holes spaced 36° apart?

4. Using the table provided, how many turns or holes would be moved for the following divisions?

____ 11

____ 228

____ 56

No. of Divisions	Circle	Turns	Holes	No. of Divisions	Circle	Turns	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes	No. of Divisions	Circle	Holes
2	any	20		23	46	1	34	44	66	60	68	34	20	104	39	15	150	30	8	205	41	8	280	28	4
3	24	13	8	24	24	1	16	45	54	48	70	28	16	105	42	16	152	38	10	210	42	8	290	58	8
4	any	10		25	25	1	15	46	46	40	72	54	30	106	53	20	155	62	16	212	53	10	296	37	5
5	any	8		26	39	1	21	47	47	40	74	37	20	108	54	20	156	39	10	215	43	8	300	30	4
6	24	6	16	27	54	1	26	48	24	20	75	30	16	110	66	24	160	28	7	216	54	10	304	38	5
7	28	5	20	28	42	1	18	49	49	40	76	38	20	112	28	10	164	41	10	220	66	12	310	62	8
8	any	5		29	58	1	22	50	25	20	78	39	20	114	57	20	165	66	16	224	28	5	312	39	5
9	54	4	24	30	24	1	8	51	51	40	80	34	17	115	46	16	168	42	10	228	57	10	320	24	3
10	any	4		31	62	1	18	52	39	30	82	41	20	116	58	20	170	34	8	230	46	8	328	41	5
11	66	3	42	32	28	1	7	53	53	40	84	42	20	118	59	20	172	43	10	232	58	10	330	66	8
12	24	3	8	33	66	1	14	54	54	40	85	34	16	120	66	22	176	66	15	235	47	8	336	42	5
13	39	3	3	34	34	1	6	55	66	48	86	43	20	124	62	20	180	54	12	236	59	10	340	34	4
14	49	2	42	35	28	1	4	56	28	20	88	66	30	125	25	8	184	46	10	240	66	11	344	43	5
15	24	2	16	36	54	1	6	57	57	40	90	54	24	130	39	12	185	37	8	245	49	8	360	54	6
16	24	2	12	37	37	1	3	58	58	40	92	46	20	132	66	20	188	47	10	248	62	10	368	46	5
17	34	2	12	38	38	1	2	59	59	40	94	47	20	135	54	16	190	38	8	250	25	4	370	37	4
18	54	2	12	39	39	1	1	60	42	28	95	38	16	136	34	10	192	24	5	255	51	8	376	47	5
19	38	2	4	40	any	1		62	62	40	96	24	10	140	28	8	195	39	8	260	39	6	380	38	4
20	any	2		41	41		40	64	24	15	98	49	20	144	54	15	196	49	10	264	66	10	390	39	4
21	42	1	38	42	42		40	65	39	24	100	25	10	145	58	16	200	30	6	270	54	8	392	49	5
22	66	1	54	43	43		40	66	66	40	102	51	20	148	37	10	204	51	10	272	34	5	400	30	3

Credit: Cincinnati Milacron

5. Which hole circle would be used for the following divisions?

____ 11

____ 228

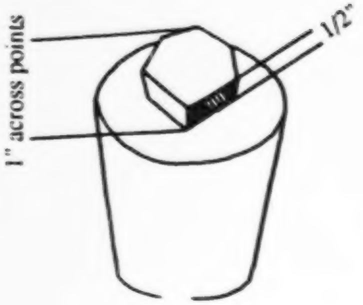
____ 56

JS 2.1

MILL WORKPIECE USING AN INDEXING HEAD

Equipment:

Dividing head with chuck
1/2" end mill
T-bolts
Dial test indicator
Workpiece (1" diameter round stock, 3-4" long)



		Evaluation			
Procedure:		3	2	1	N
1.	Align and mount dividing head onto milling table so that the dividing head spindle is parallel to the table.	___	___	___	___
2.	Mount workpiece in chuck with about 1 1/2" extending beyond the jaws.	___	___	___	___
3.	Swivel head into vertical position. Using dial indicator, center spindle over workpiece center.	___	___	___	___
4.	Move the table a distance equal to the distance from the center of the workpiece to the flat on the hexagon, plus one half the cutter diameter.	___	___	___	___
5.	Engage spindle. Raise knee until cutter grazes end of workpiece. Clear workpiece using transverse table movement. Set depth of cut. Apply coolant as needed. Machine the first flat.	___	___	___	___
6.	Using the index plate with a 24-hole circle, turn the index crank six turns. The workpiece is now in position for machining the next flat.	___	___	___	___
7.	Continue machining until hexagon is completed.	___	___	___	___
8.	Clean up area and return tools and materials.	___	___	___	___
Average of above evaluations*		___	___	___	___

*This average is the student's final evaluation for competency J22: Mill workpiece using simple indexing operation.

MODULE: MILLING

UNIT XI: ROTARY TABLES AND INDEXING

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. The angular graduations on a rotary table are in which units?

a. Degrees
b. 1/2 degrees
c. 1/1000 inch
d. .05 mm
e. 10 degrees

____ 2. When mounting a rotary table to the milling table, what is used to ensure proper alignment?

a. Dial indicator
b. Bench rule
c. Inside micrometer
d. Vernier gage
e. None of the above

____ 3. When machining a radius with the rotary table, how is feed accomplished?

a. Turning the rotary table hand crank
b. Engaging the quill feed
c. Transverse feed
d. Spindle motor
e. None of the above

____ 4. Which of the following is an operation not well suited to the dividing head?

a. Direct indexing
b. Simple indexing
c. Machining of a gear or spline
d. Internal boring
e. All of the above

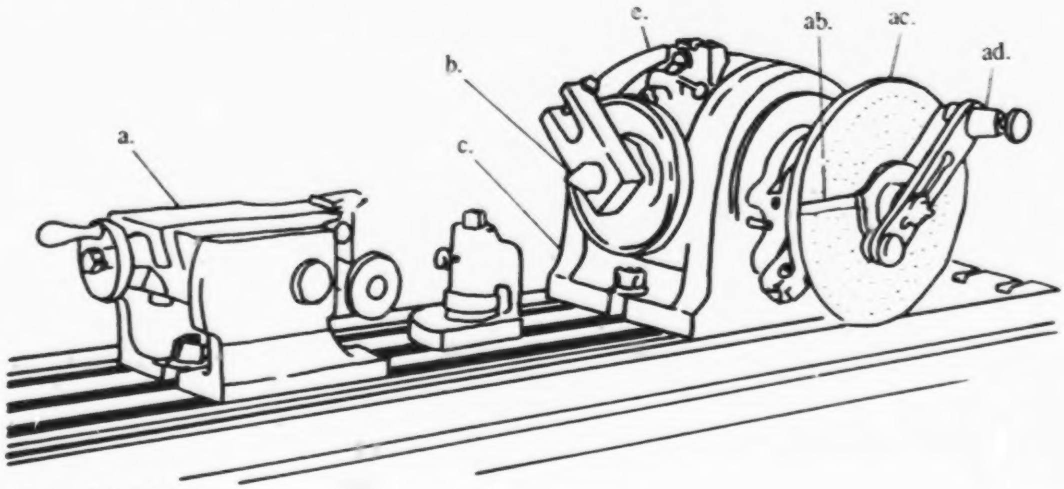
____ 5. For direct indexing, what is the ratio of movement of the crank to the spindle?

a. 1:1
b. 2:1
c. 24:1
d. 40:1
e. 56:1

____ 6. How many divisions does the direct indexing plate have?

a. 2
b. 13
c. 14
d. 18
e. 24

Identify the parts of the index head shown below.



____ 7. Spindle

____ 8. Side index plate

____ 9. Index crank

____ 10. Tailstock

Select the option which answers the question or completes the statement.

____ 11. Which of the following indexing divisions would not be attainable by direct indexing?

a. 2
b. 3
c. 4
d. 13
e. 24

____ 12. In simple indexing, what ratio of crank to spindle movement does the worm gear provide?

a. 1:1
b. 2:1
c. 40:1
d. 56:1
e. None of the above

____ 13. In angular indexing, one revolution of the crank yields how much spindle movement?

a. 1°
b. 2°
c. 3:1
d. 9°
e. 40°

____ 14. What is the purpose of the sector arms?

a. Limit motion of spindle to prescribed tolerances
b. Limit motion of indexing crank to 1/40 turn only
c. To prescribe the circumference of the workpiece
d. To permit setting of fractional portions of a turn
e. None of the above

ANSWERS TO UNIT TEST

1.	b	(J20, 21)
2.	a	(J20, 21)
3.	a	(J20, 21)
4.	d	(J22)
5.	a	(J22)
6.	e	(J22)
7.	b	
8.	ac	
9.	ad	
10.	a	
11.	d	(J22)
12.	c	(J22)
13.	d	(J22)
14.	d	(J22)

MODULE: MILLING

UNIT XII: HORIZONTAL MILLING OPERATIONS

UNIT OBJECTIVE

In this unit the student will learn three important horizontal milling operations: straddle milling, gang milling and gear cutting. The student will learn to select gear cutters and to read a vernier gear caliper to measure gears. Finally, the student will machine with an indexing head to form a spur gear. This knowledge will be evidenced by achieving the specified score on job sheets and the unit test.

SPECIFIC OBJECTIVES

Upon completion of the lessons in this unit, the student should be able to:

1.1 Identify terms and definitions pertaining to straddle milling, gang milling, gear terminology, measurement and machining.

1.2 Perform straddle milling. (competency J24, JS 1.1)

1.3 Perform gang milling. (competency J25, JS 1.2)

2.1 Identify terms and definitions related to gears and gear cutting.

2.2 Identify types of gears and their applications.

2.3 Calculate gear variables using formulas provided. (AS 2.1)

2.4 Read a vernier gear caliper for the purpose of gear measurement.

2.5 Perform gear cutting operations by machining a spur gear. (competency J26, JS 2.1)

MODULE: MILLING

UNIT XII: HORIZONTAL MILLING OPERATIONS

CONTENTS OF THIS UNIT

A. Objective sheet

B. References

C. Notes to the instructor

D. Lesson plans

  1. Lesson 1: STRADDLE AND GANG MILLING

    a. Information outline

    b. Job sheets

      JS 1.1: Perform straddle milling
      JS 1.2: Perform gang milling

  2. Lesson 2: GEARS AND GEAR CUTTING

    a. Information outline

    b. Transparency masters

      TM 2.1: Methods of gauging gears
      TM 2.2: Spur gear milling

    c. Handout

      HO 2.1: Gear types and features

    d. Assignment sheet

      AS 1.1: Gear calculations

    e. Job sheet

      JS 2.1: Perform gear cutting operations by machining a spur gear

E. Unit test

F. Answers to unit test

REFERENCES

A. Books

1. Olivo, C. Thomas. Advanced Machine Tool Technology. North Scituate, MA: Breton Publishers, a division of Wadsworth, Inc., 1982.

2. Repp, Victor E., and Willard J. McCarthy. Machine Tool Technology. 5th ed. Bloomington, IL: McKnight Publishing Co., 1984.

B. Curriculum guides/materials

1. Apprentice Machinist (AFSC 53130). Vol. I. Machine Shop Fundamentals. Gunter Air Force Base, AL: Extension Course Institute, Air University, 1981.

2. "Machine Shop Milling Transparencies." College Station: Vocational Instructional Services, Texas A & M University, 1980.

3. Benson, Robert T., and Margaret R. Gregory. V-TECS Guide for Machine Shop. Columbia, SC: South Carolina Department of Education, 1985.

4. Dunn, James. Machine Shop I. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1981.

5. Dunn, James. Machine Shop Milling Machines. Stillwater: Curriculum and Instructional Materials Center, Oklahoma State Board of Vocational and Technical Education, 1983.

6. Grimes, L. Machinist. Austin: Center for Occupational Curriculum Development, University of Texas at Austin, 1982.

7. Yettaw, Jerome. Vocational Machine Shop. University of Missouri-Columbia: Instructional Materials Laboratory, 1977.

C. Other references

1. "1983 Mechanical Drives Reference Issue." Machine Design 30 June 1983.

2. "Bridgeport Machines Operator's Manual." Bridgeport, CT: Bridgeport Machines, Inc., n.d.

NOTES TO THE INSTRUCTOR

A. Suggested approaches to teaching this unit

1. Job sheets in this unit provide general guidelines for the operations to be performed. The actual workpiece produced will be determined by cutters available in your shop.

MODULE: MILLING

UNIT XII: HORIZONTAL MILLING OPERATIONS

LESSON 1: STRADDLE AND GANG MILLING

I. Terms

A. Gang milling--using two or more milling cutters adjacent to one another to machine a desired feature on a part.

B. Half-side milling cutter--a cutter having teeth on the periphery and one side only; may be left- or right-hand configuration

C. Plain milling cutter--has teeth on the periphery only

D. Plain side milling cutter--has teeth on its periphery and on its side

E. Straddle milling--employs two side milling cutters used to machine two parallel sides of an object simultaneously. The distance between each cutter is set with spacers.

II. Procedure for straddle milling

A. Determine width of feature to be straddle milled from blueprint.

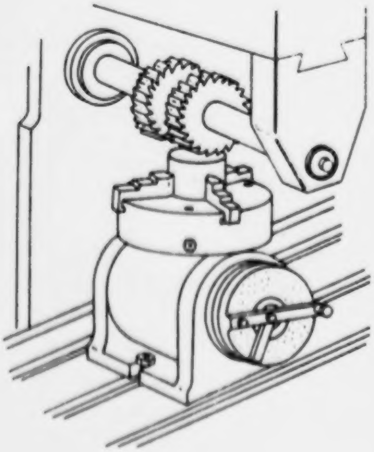
B. Obtain left, right and side milling cutters and necessary spacers to obtain the desired distance between the cutters. Mount on arbor.

NOTE: Remember to tighten the arbor nut only when the end of the arbor is mounted in the arbor support. The arbor can be bent if done otherwise.

C. Mount workpiece in vise.

D. Align cutter with workpiece. Select and set appropriate speed and feed.

E. Apply coolant. Start cut with shallow depth. Raise knee on successive passes until desired depth of cut is obtained.



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III. Procedure for gang milling

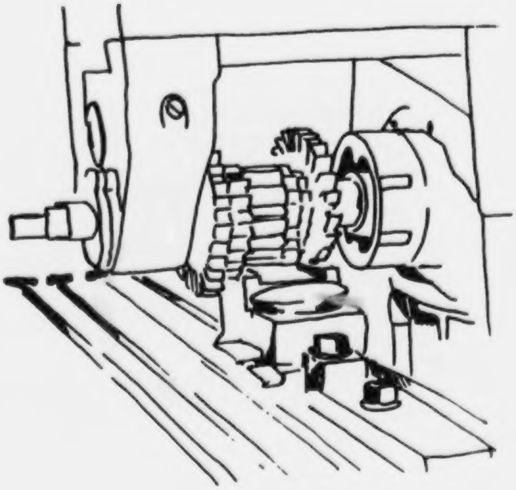
A. Obtain necessary cutters to achieve desired part geometry.

B. Mount cutters on arbor.

C. Mount workpiece in vise.

D. Align cutter with workpiece. Select and set desired speed and feed.

E. Apply coolant. Start cut with shallow depth. Raise knee on successive passes until desired depth is obtained.



Gang milling

JS 1.1

PERFORM STRADDLE MILLING

Equipment:

Horizontal milling arbor
Arbor support
Various arbor spacers
Right- and left-hand side milling cutters
Vernier caliper
Depth micrometer
Dial indicator
Milling vise
Workpiece material

		Evaluation			
	Procedure:	3	2	1	N
1.	Align milling vise to table with dial indicator.	___	___	___	___
2.	Determine width of feature to be straddle milled from blueprint.	___	___	___	___
3.	Obtain left, right and side milling cutters and necessary spacers to obtain the desired distance between the cutters. Mount on arbor.	___	___	___	___

NOTE: Remember to tighten the arbor nut only when the end of the arbor is mounted in the arbor support. The arbor can be bent if done otherwise.

		3	2	1	N
4.	Mount and align workpiece in vise.	___	___	___	___
5.	Align and center cutter with workpiece. Select and set appropriate speed and feed.	___	___	___	___
6.	Apply coolant. Graze top of workpiece. Start cut with shallow depth. Raise knee on successive passes until desired depth of cut is obtained.	___	___	___	___
7.	Check width of feature with vernier caliper. Check depth of step with micrometer depth gage.	___	___	___	___
8.	As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.	___	___	___	___
	Average of above evaluations*	___	___	___	___

*This average is the student's final evaluation for competency J24: Machine workpiece by straddle milling

PERFORM GANG MILLING

Equipment:

Horizontal milling arbor
Arbor support
Various arbor spacers
Right- and left-hand side milling cutters
Plain milling cutter
Vernier caliper
Depth micrometer
Dial indicator
Milling vise
Workpiece material

		Evaluation			
Procedure:		3	2	1	N
1.	Obtain necessary cutters to achieve desired part geometry as described on blueprint.	_	_	_	_
2.	Obtain left, right and side milling cutters and plain milling cutter necessary to cbtain the desired part geometry. Mount on arbor.	_	_	_	_
	NOTE: Remember to tighten the arbor nut only when the end of the arbor is mounted in the arbor support. The arbor can be bent if done otherwise.				
3.	Mount and align workpiece in vise.	_	_	_	_
4.	Align and center cutter with workpiece. Select and set appropriate speed and feed.	_	_	_	_
5.	Apply coolant. Graze top of workpiece. Start cut with shallow depth. Raise knee on successive passes until desired depth of cut is obtained.	_	_	_	_
6.	Check width of feature with vernier caliper. Check depth of step with micrometer depth gage.	_	_	_	_
7.	As directed by instructor, prepare for next job sheet or clean up area and return tools and materials.	_	_	_	_
Average of above evaluations*		_	_	_	_

*This average is the student's final evaluation for competency J25: Perform gang milling.

MODULE: MILLING

UNIT XII: HORIZONTAL MILLING OPERATIONS

LESSON 2: GEARS AND GEAR CUTTING

I. Gear terms

  A. Tooth form--tooth geometry determined primarily by depth, pressure angle and pitch

  B. Chordal thickness--thickness of a gear tooth at the pitch line

  C. Module--two systems for determining the distance between gear teeth (See also pitch diameter.)

    1. English module--represents the ratio of the pitch diameter to the number of teeth on the gear

    2. Metric module--actual distance obtained by dividing the pitch diameter by the number of teeth

  D. Depth--standardized to pitch, standard full-depth = 2 ÷ P

  E. Pitch--circular distance between two corresponding points on adjacent gear teeth measured at the pitch circle. Also, the spacing of the teeth along the pitch circle

  F. Pitch circle--imaginary circle representing the point at which the teeth on two mating gears are tangent. Two mating gears can be thought of as smooth cylinders in contact as they roll, the diameter at the point of contact is the **pitch diameter.**

  G. Addendum--height of the gear tooth above the pitch circle

  H. Dedendum--depth of the tooth below the pitch circle

  I. Total gear depth--sum of the addendum and the dedendum

  J. Working depth--depth of engagement of teeth on mating gears; the sum of the two addenda; the depth to which gears are cut

  K. Involute form--basis of most gear tooth geometry; curve described as path made by a point on a cord or string as it is held taut and unwrapped from a cylinder

  L. Base circle--circle from which the involute is generated

  M. Pressure angle--angle formed by a line tangent to both the pitch circle and the base circle

II. Types of gears and applications **(HO 2.1)**

- A. Spur gears--most common type; straight and parallel teeth parallel to axis of shaft; low-cost, easy to manufacture and maintain
- B. Helical--teeth at an angle to the shaft; carry more load than comparable spur gears and operate more smoothly; more expensive to manufacture
- C. Bevel gear--gears used to transmit power between two shafts at right angles
- D. Worm and gear--set consisting of a worm (thread-like helical gear form on a shaft) and spur gear; used to change the direction of power transmission and for high-torque applications

III. Gear formulas

- A. Accurate machining of gears requires control of many features of the gear.
- B. Dimensions of these features can be found in tables in handbooks or as calculated as below.

Spur Gear Formulas for American National Standard 20° and 25° Full-Depth Tooth Forms

To find	Given	Formula (dimensions in inches)
1. Number of teeth	Diametral pitch and pitch diameter	$N = DP \times PD$
2. Number of teeth	Diametral pitch and outside diameter	$N = (DP \times OD) - 2$
3. Pitch diameter	Diametral pitch and number of teeth	$PD = \frac{N}{DP}$
4. Pitch diameter	Outside diameter and addendum	$PD = OD - 2A$
5. Outside diameter	Diametral pitch and number of teeth	$OD = \frac{N + 2}{DP}$
6. Outside diameter	Pitch diameter and number of teeth	$OD = \frac{N + 2}{\frac{N}{PD}}$
7. Whole depth of tooth	Diametral pitch	$WD = \frac{2.250}{DP}$
8. Clearance	Diametral pitch	$C = \frac{0.250}{DP}$
9. Thickness of tooth	Diametral pitch	$CT = \frac{1.5708}{DP}$
10. Diametral pitch	Circular pitch	$DP = \frac{3.1416}{CP}$
11. Diametral pitch	Pitch diameter and number of teeth	$DP = \frac{N}{PD}$
12. Diametral pitch	Outside diameter and number of teeth	$DP = \frac{N + 2}{OD}$
13. Circular pitch	Diametral pitch	$CP = \frac{3.1416}{DP}$
14. Circular pitch	Number of teeth and pitch diameter	$CP = \frac{PD}{0.3183N}$
15. Center distance	Pitch diameters	$CD = \frac{PD + pd}{2}$
16. Center distance	Diametral pitch and number of teeth	$CD = \frac{\frac{1}{2}(N + n)}{DP}$

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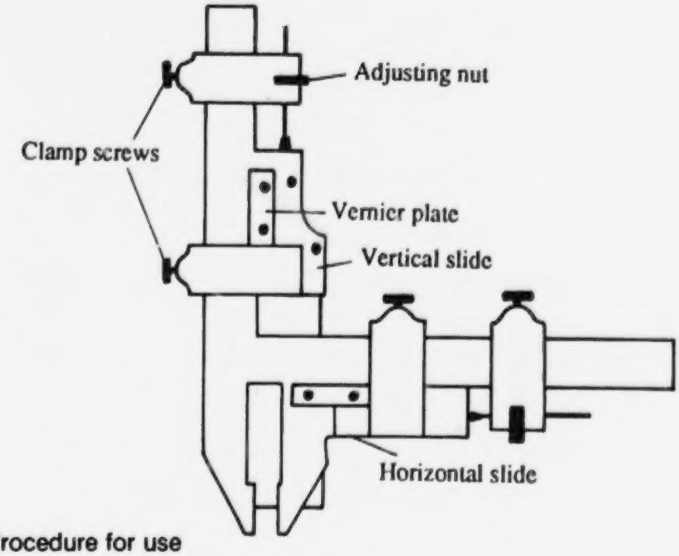
IV. Gear measurement and inspection (TM 2.1)

A. Gear tooth vernier--special-purpose caliper designed to measure chordal thickness of the gear tooth at the pitch circle and distance from the of the tooth to the pitch circle (addendum); functions as both a vernier depth gage and a vernier caliper

1. Parts of the gear tooth vernier



2. Procedure for use

a. Determine desired addendum and chordal thickness by calculation or from standard tables.

b. Set vertical slide to desired addendum. Caliper is now positioned across pitch line.

NOTE: Addendum setting may need to be adjusted for any variations in gear blank diameter.

c. Use horizontal slide to measure chordal thickness of tooth.

B. Two-wire method--similar to that used to measure threads. A micrometer measurement is taken over to wires of a specified diameter to test the accuracy of the gear teeth.

V. Procedure for milling a spur gear (TM 2.2)

A. Select gear tooth cutter.

B. Mount dividing head. If gear blank is to held on a mandrel, it will be necessary to mount and align the tailstock, as well.

C. To ensure maximum rigidity of the setup, position gear cutter on arbor as close to the machine column as possible.

D. Mount gear blank.

E. Align center line of gear cutter with center line of gear blank. Lock cross-slide.

F. Mount appropriate index plate to achieve desired number of teeth.

G. Apply coolant. Start spindle. Raise knee until cutter grazes the workpiece. Set knee micrometer dial to zero.

H. Clear cutter. Set depth to 3/4 of full depth. Lock knee.

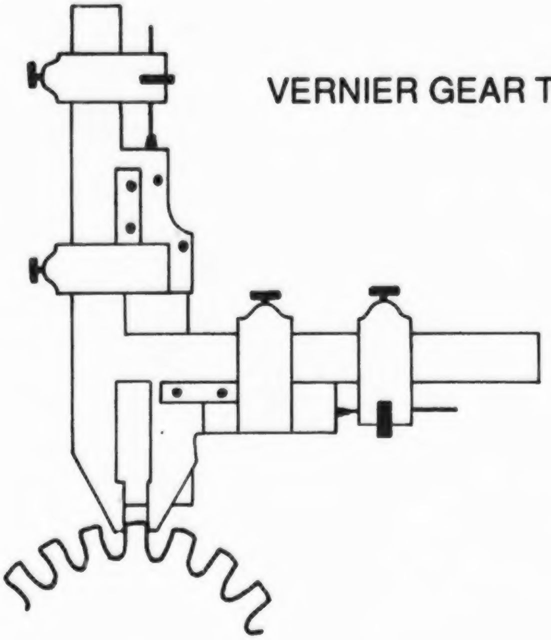
I. Rough out first tooth. Return cutter to start. Index for next tooth and rough out. Continue until all teeth have been rough cut.

CAUTION: Always stop spindle before indexing or making any other machine adjustments.

J. Raise knee to full depth. Cut all teeth to full depth.

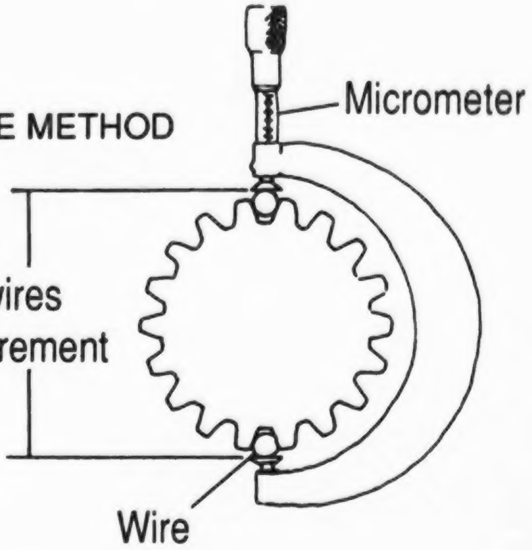
NOTE: It may be desirable to inspect the first finished tooth with a gear tooth vernier before proceeding with the other teeth.

METHODS OF GAUGING GEARS

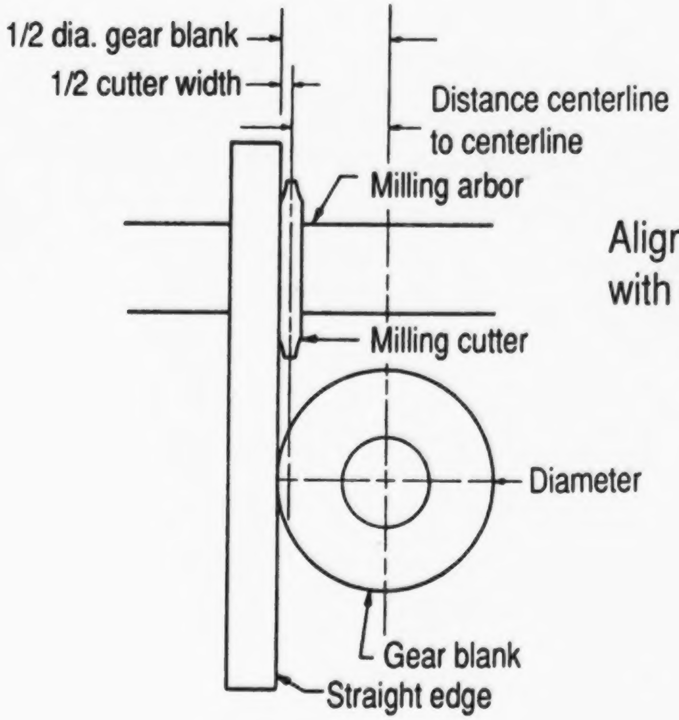


VERNIER GEAR TOOTH CALIPER

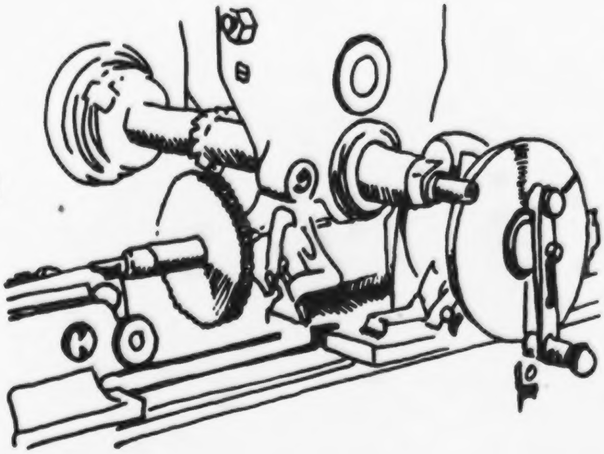
MEASUREMENT WITH TWO-WIRE METHOD


Micrometer
Over-wires measurement
Wire

SPUR GEAR MILLING


1/2 dia. gear blank
1/2 cutter width
Distance centerline to centerline
Milling arbor
Milling cutter
Diameter
Gear blank
Straight edge

Aligning side of gear cutter with side of gear blank



Cutting spur gear teeth

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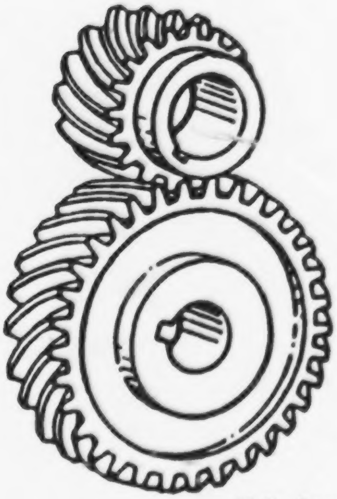
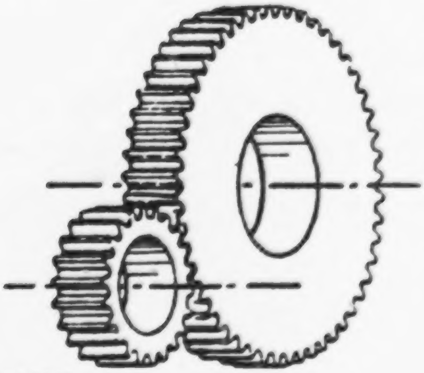
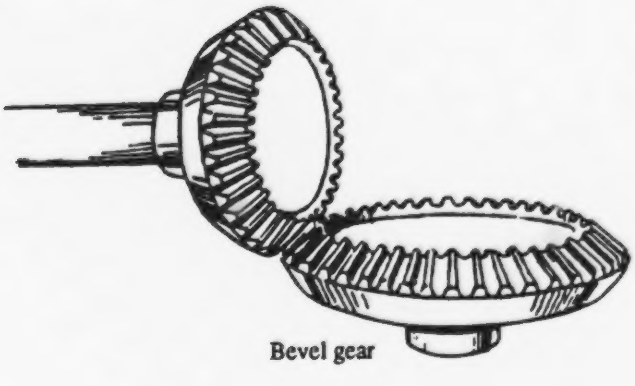
GEAR TYPES AND FEATURES



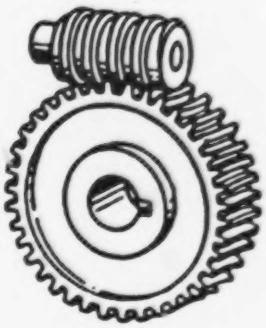
Helical gear



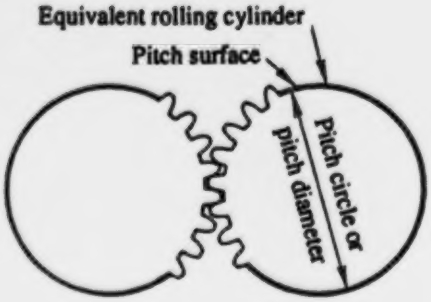
Spur gear

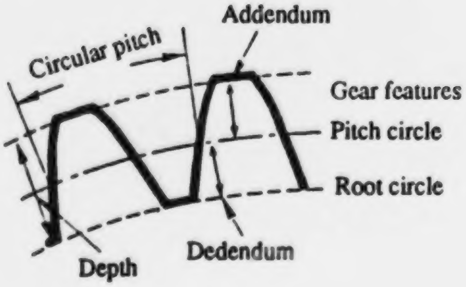


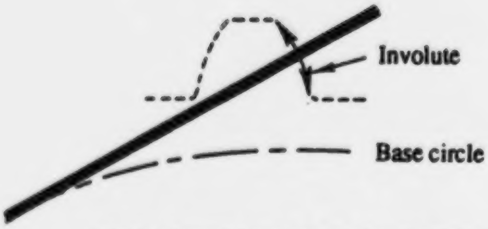
Bevel gear



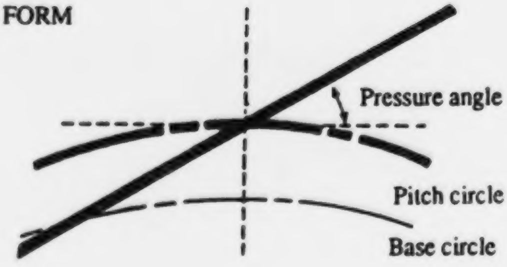
Worm and gear


Equivalent rolling cylinder
Pitch surface
Pitch circle or pitch diameter


Addendum
Circular pitch
Gear features
Pitch circle
Root circle
Depth
Dedendum


Involute
Base circle

FORMATION OF INVOLUTE TOOTH FORM


Pressure angle
Pitch circle
Base circle

DETERMINATION OF PRESSURE ANGLE

Credit: Partially reprinted from "1983 Mechanical Drives Reference Issue." Machine Design. Cleveland, OH: Penton Publishing Inc., 30 June 1983. © 1983

GEAR CALCULATIONS

Calculate the following for a 20 diametral pitch gear with a 4" pitch diameter. Show all work.

1. Number of teeth $N = D.P. \times P.D.$

2. Outside diameter $\dfrac{N + 2}{N \div P.D.} = O.D.$

3. Addendum $\dfrac{1.0.}{D.P.}$

4. Dedendum $\dfrac{1.25}{D.P.}$

5. Full depth $W.D. = \dfrac{2.250}{D.P.}$ or addendum + dedendum

6. Chordal (circular) tooth thickness

$$C.T. = \frac{1.570}{D.P.}$$

ANSWERS TO ASSIGNMENT SHEET 1.1

1. 80 teeth
2. O.D. = 4.1"
3. Addendum = .05"
4. Dedendum = 0.0625
5. W.D. = .1125
6. C.T. = 0.0785

JS 2.1

PERFORM GEAR CUTTING OPERATIONS BY MACHINING A SPUR GEAR

Equipment:

Dividing head with tailstock
Mandrel to fit hole in gear blank
Gear blank
Horizontal milling arbor
Arbor support
Vernier caliper
Dial indicator
Vernier gear caliper

Procedure:		Evaluation 3	2	1	N
1.	Calculate outside diameter of gear blank and measure to be sure blank is the proper size.	___	___	___	___
2.	Calculate addendum and chordal thickness of teeth to be machined.	___	___	___	___
3.	Select gear tooth cutter.	___	___	___	___
4.	Mount dividing head. If gear blank is to held on a mandrel, it will be necessary to mount and align the tailstock, as well.	___	___	___	___
5.	Position gear cutter on arbor as close to the machine column as possible.	___	___	___	___
6.	Mount gear blank. Use arbor press to secure gear blank to the mandrel. Use dog to secure mandrel to dividing head.	___	___	___	___
7.	Align center line of gear cutter with center line of gear blank. Lock cross-slide.	___	___	___	___
8.	Mount appropriate index plate to achieve desired number of teeth.	___	___	___	___
9.	Apply coolant. Start spindle. Raise knee until cutter grazes the workpiece. Set knee micrometer dial to zero.	___	___	___	___
10.	Clear cutter. Set depth to 3/4 of full depth. Lock knee.	___	___	___	___
11.	Rough out first tooth. Return cutter to start. Index for next tooth and rough out. Continue until all teeth have been rough cut.	___	___	___	___
	CAUTION: Always stop spindle before indexing or making any other machine adjustments.				
12.	Raise knee to full depth. Cut one tooth to full depth. Inspect the first finished tooth with a gear tooth vernier. Check against calculated values.	___	___	___	___
13.	Finish machine the remaining teeth.	___	___	___	___

14. As directed by instructor, prepare for next job sheet or clean up area and return tools and materials. __ __ __ __

Average of above evaluations* __ __ __ __

*This average is the student's final evaluation for competency J26: Perform gear cutting operations.

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MODULE: MILLING

UNIT XII: HORIZONTAL MILLING OPERATIONS

UNIT TEST

Select the option which answers the question or completes the statement.

____ 1. Which type of milling uses two side milling cutters to machine the side of a workpiece simultaneously?

a. End
b. Face
c. Gang
d. Straddle
e. None of the above

____ 2. What is the minimum number of cutters used in gang milling?

a. 1
b. 2
c. 3
d. 4
e. 5

____ 3. Which type of cutter is available in either a left- or right-hand configuration and has teeth on only one side?

a. Gang milling cutter
b. Half-side milling cutter
c. Semi-mill
d. End mill
e. Plain milling cutter

____ 4. In straddle milling, how is the distance between the cutters determined?

a. Use spacers
b. Apply soluble coolant to minimize workpiece distortion
c. Cross-slide feed
d. Overarm setting
e. None of the above

Match terms with the definitions below.

____ 5. Geometry determined primarily by depth, pressure angle and pitch

____ 6. Thickness of a gear tooth at the pitch line

____ 7. Height of the gear tooth above the pitch circle

____ 8. Depth of engagement of teeth on mating gears; the sum of the two addenda; depth to which gears are cut

____ 9. Basis of most gear tooth geometry; curve described as path made by a point on a cord or string as it is held taut and unwrapped from a cylinder

____ 10. Formed by a line tangent to both the pitch circle and the base circle

a. Addendum

b. Chordal thickness

c. Dedendum

d. Involute form

e. Pressure angle

ab. Tooth form

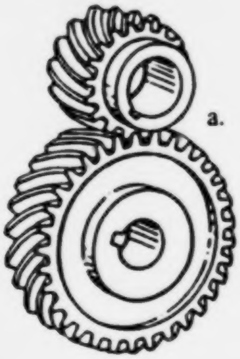
ac. Working depth

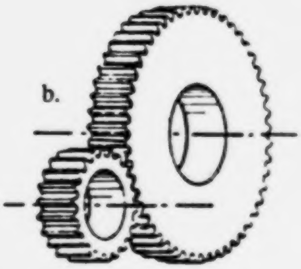
Match the gear types listed with the appropriate illustration.

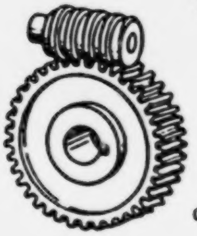
____ 11. Spur gear

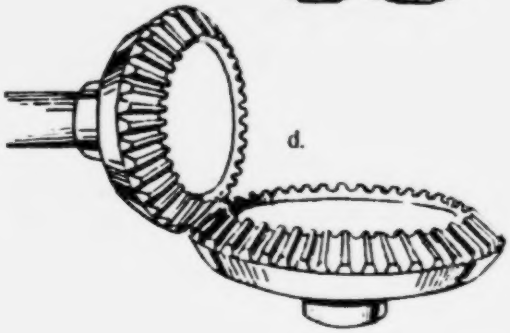
____ 12. Bevel gear

____ 13. Helical gear


a.


b.


c.


d.

Select the option which answers the question or completes the statement.

____ 14. What is the most common type of gear?

a. Spur gear
b. Involute helical
c. Helical
d. Worm
e. None of the above

____ 15. Which type of gear uses a thread-like gear form cut into a shaft?

a. Spur
b. Gear and worm
c. Hypoid
d. Planetary gearbox
e. None of the above

____ 16. Which type of gear would be used to transmit power between two shafts at right angles?

a. Spur
b. Bevel
c. Helical
d. Cycloid
e. None of the above

____ 17. The gear tooth vernier is used to measure which of the following pair of gear features?

a. Diameter and chord
b. Chordal thickness and addendum
c. Chordal thickness and dedendum
d. Outside diameter and hub
e. Chordal perimeter and addendum

____ 18. What is used for proper machining of teeth on a gear blank?

a. Dividing head
b. Indicator
c. Quill feed handwheel
d. Overarm attachment
e. None of the above

____ 19. Why is it advisable to mount the gear cutter as close to the column as the set-up will permit?

a. To reduce machining time
b. To increase rigidity
c. To facilitate indexing of gear blank
d. To provide for proper coolant flow
e. None of the above

____ 20. Depth of cut in gear cutting is established using which part?

a. Cross-slide
b. Knee
c. Longitudinal table feed
d. Quill feed handwheel
e. None of the above